STAR in the eRHIC Era

Ernst Sichtermann, LBNL
for the Collaboration

eRHIC, ePHENIX, eSTAR,
EIC TF, eRHIC-CAD Meeting
BNL, March 11, 2011

Why EIC?

What is the role of gluons and of gluon self-interactions in nucleons and nuclei?

Measurements: inclusive DIS structure functions,
semi-inclusive DIS,
diffraction

What is the internal landscape of the nucleon?
- its combined spatial and momentum structure?
- its spin structure?

Measurements: polarized DIS,
transverse-momentum dependent distributions
exclusive reactions, vector-meson production, DVCS

What governs the transition of from quarks and gluons to hadrons? Propagation through matter?

Measurements: (ratios of) semi-inclusive DIS cross sections, jets

Continued development of Science Case, most recently via INT 10-3

e.g. electroweak structure functions.

Needs for EIC?

Viable e + (p-A) beam collisions, polarized and unpolarized,

Viable collaborations and instruments to observe, analyze, and publish.

STAR - Decadal Plan

Steve Vigdor's to Barbara Jacak, Nu Xu, all (December 2009):

1) ... summary of ongoing upgrades

2) ... compelling science ... RHIC A+A, p+p, d+Au ... requiring upgrades

3) ... prioritized list of major upgrades ...

4) Any plans or interest your Collaboration has in adapting your detector or detector subsystems (or detector R&D) to study electron-nucleon and electron-ion collisions with an eventual eRHIC upgrade. This is relevant only near the end of the decade addressed here, but will be important for planning purposes. (We may well be forced by financial or environmental considerations, even for a first MeRHIC stage, to consider options in which acceleration of the electron beam is carried out around the RHIC tunnel, requiring some scheme for getting an electron beamline through or around PHENIX and STAR. So it's worth considering if there is some way you could make use of the e-p and e-A collisions if we provided them.)

5) ... future of collaboration ...

STAR - Today

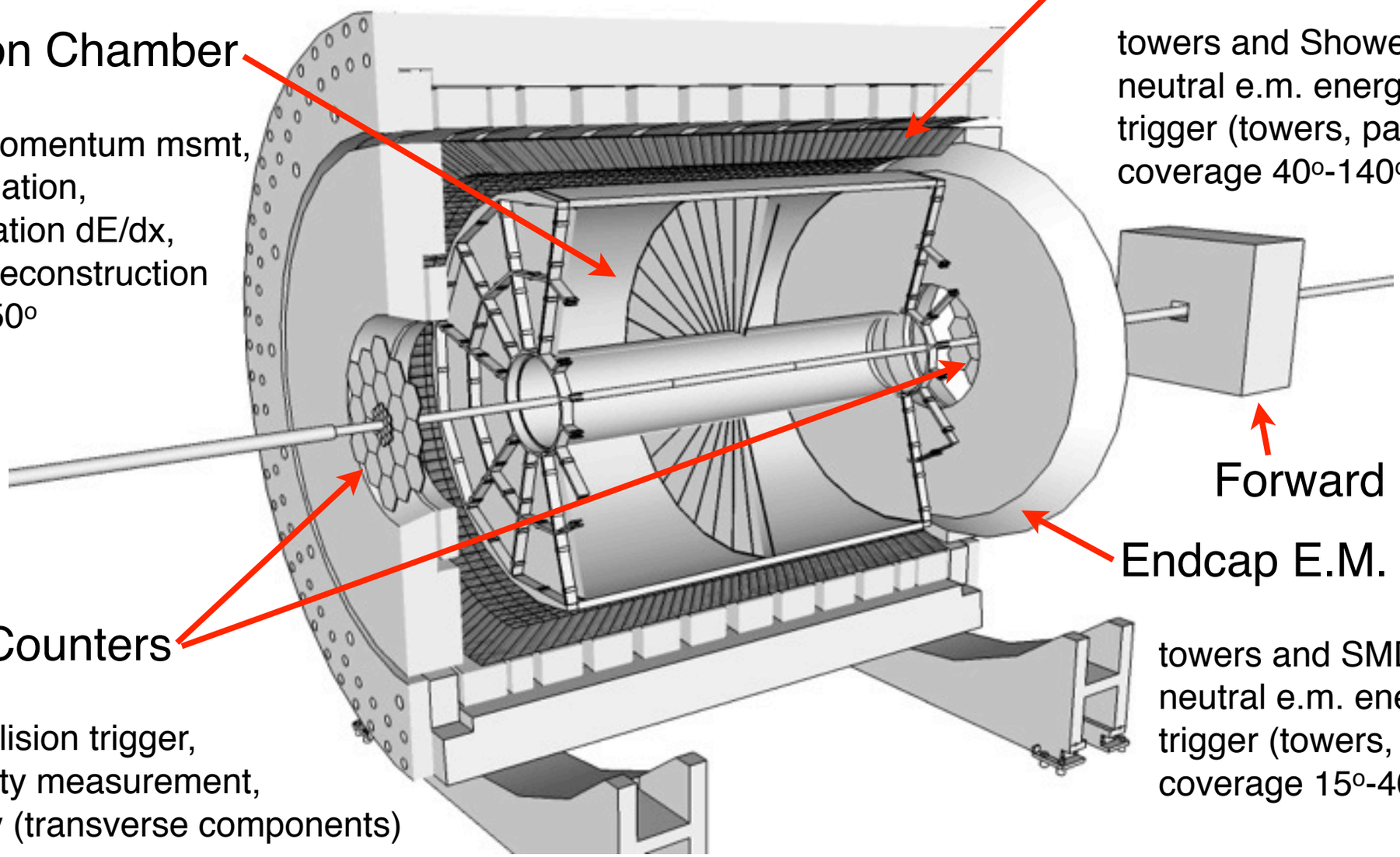
Nucl. Instrum. Meth. A499, 624, 2003

Time Projection Chamber

charged track momentum msmt,
charge determination,
particle identification dE/dx,
collision vertex reconstruction
coverage 30^o-150^o

Barrel E.M. Calorimeter

towers and Shower Maximum Det.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 40^o-140^o



Forward Meson Spectr.

Endcap E.M. Calorimeter

Beam-Beam Counters

proton beam collision trigger,
relative luminosity measurement,
local polarimetry (transverse components)

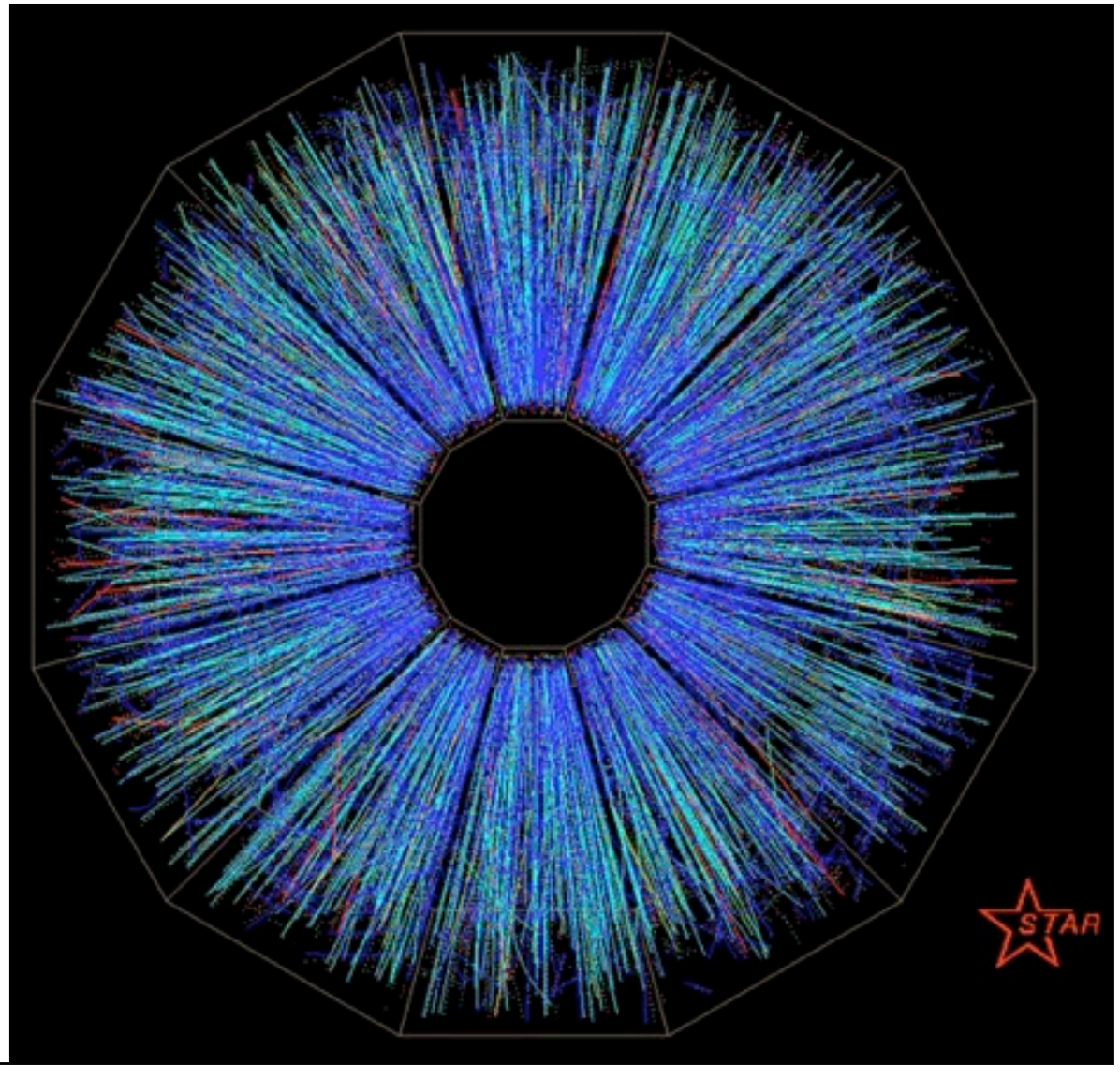
towers and SMD.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 15^o-40^o

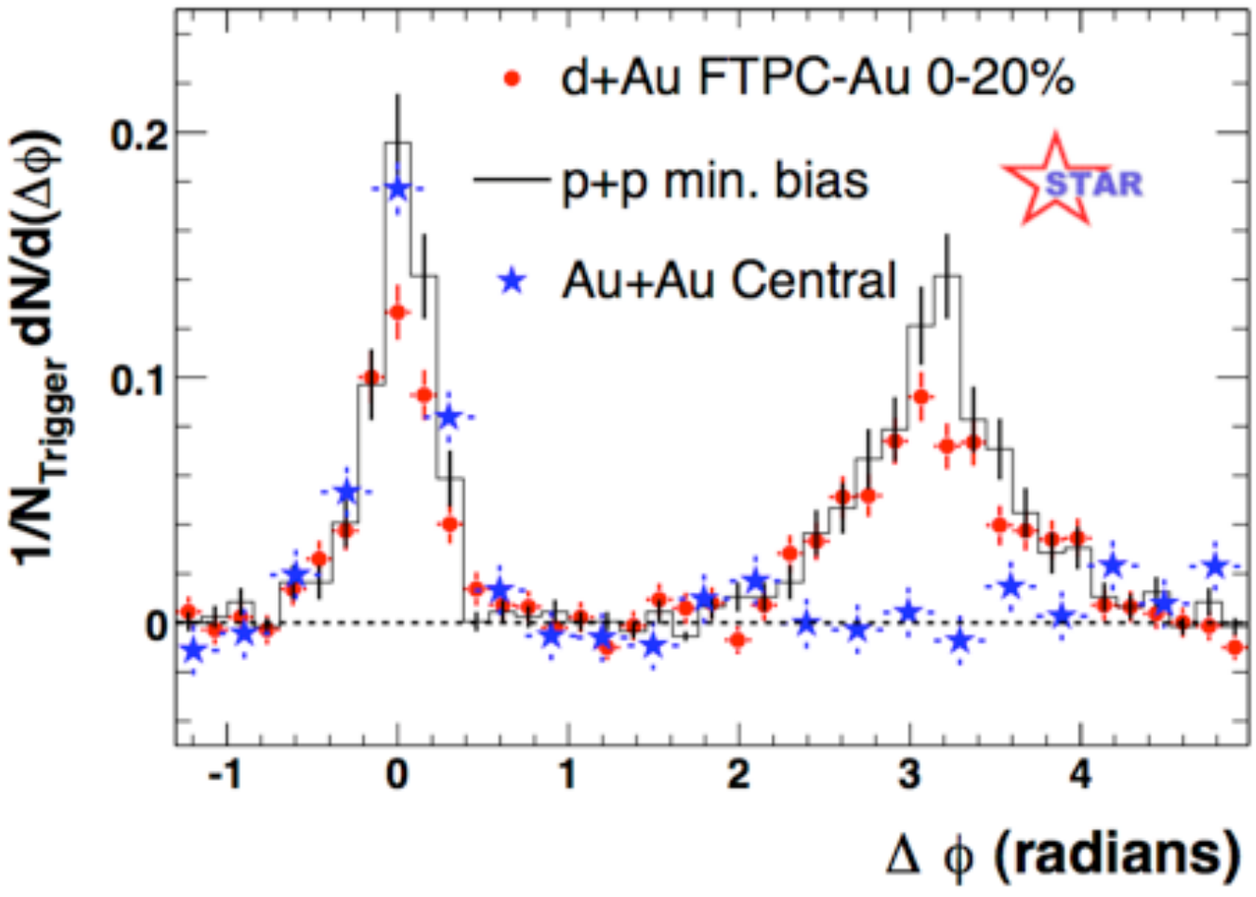
0.5 T Solenoidal Magnetic Field

Several detectors not discussed above, e.g. Time-of-Flight (complete for run-10), ZDC, RP, ...

A versatile central-rapidity instrument, and an active upgrade program,

STAR - Today



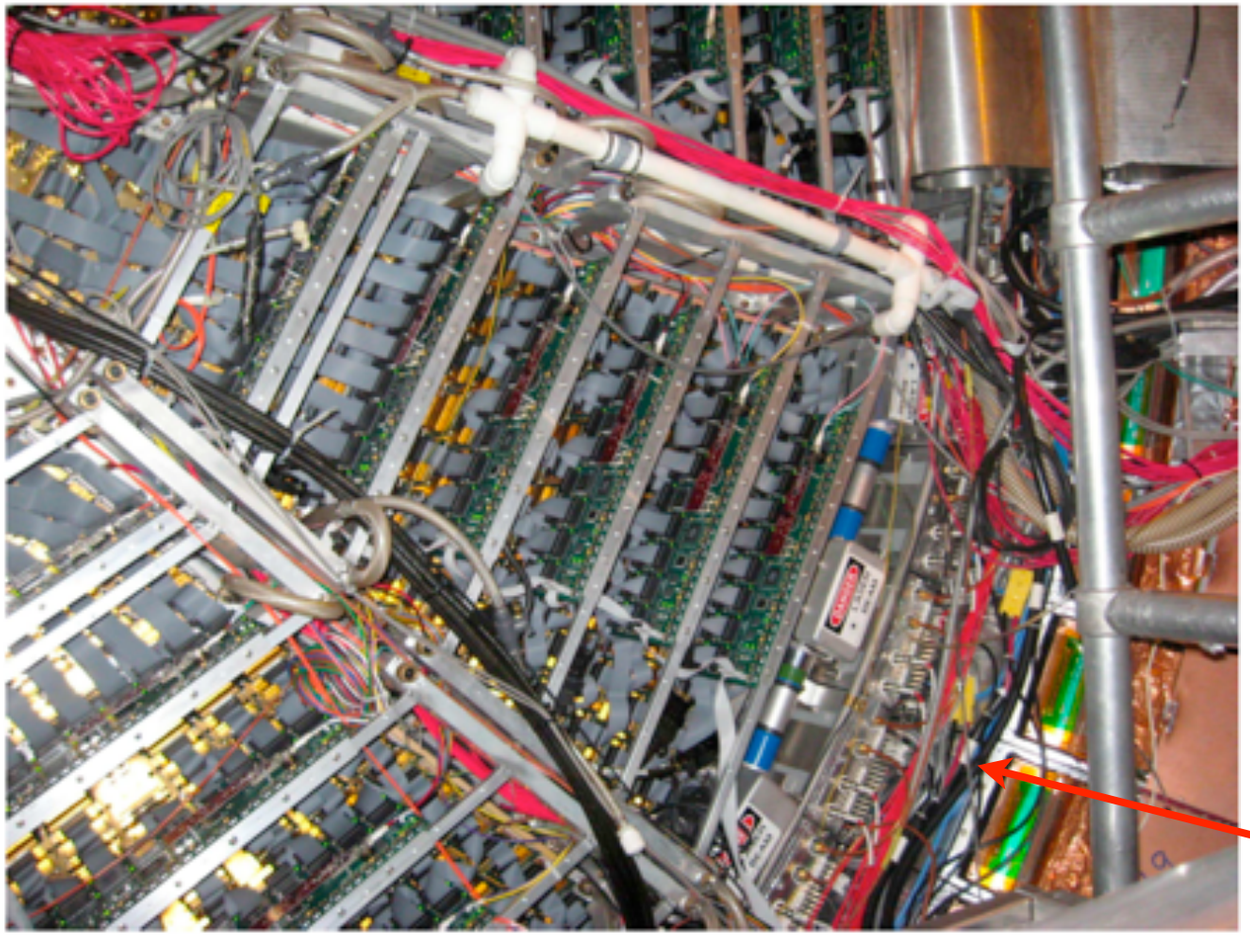


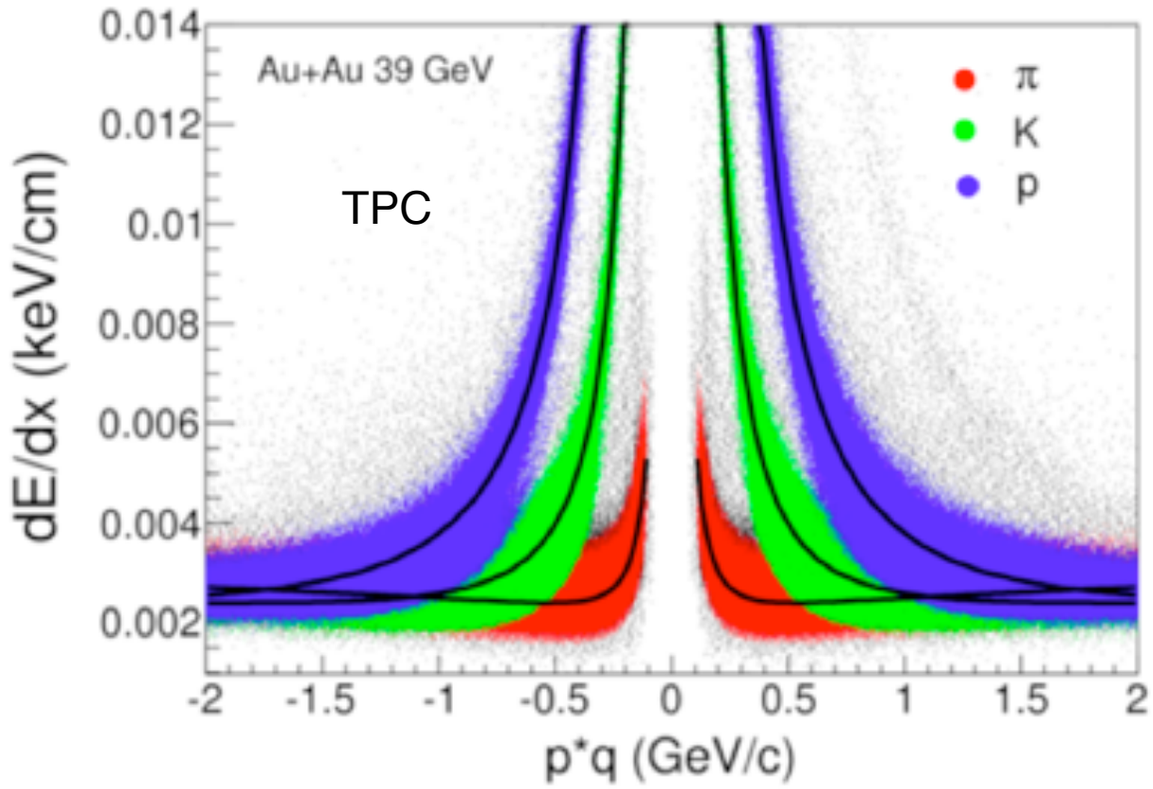
J. Adams et al., Phys.Rev.Lett.92:052302,2004,
J. Adams et al., Nucl.Phys.A757:102,2005.

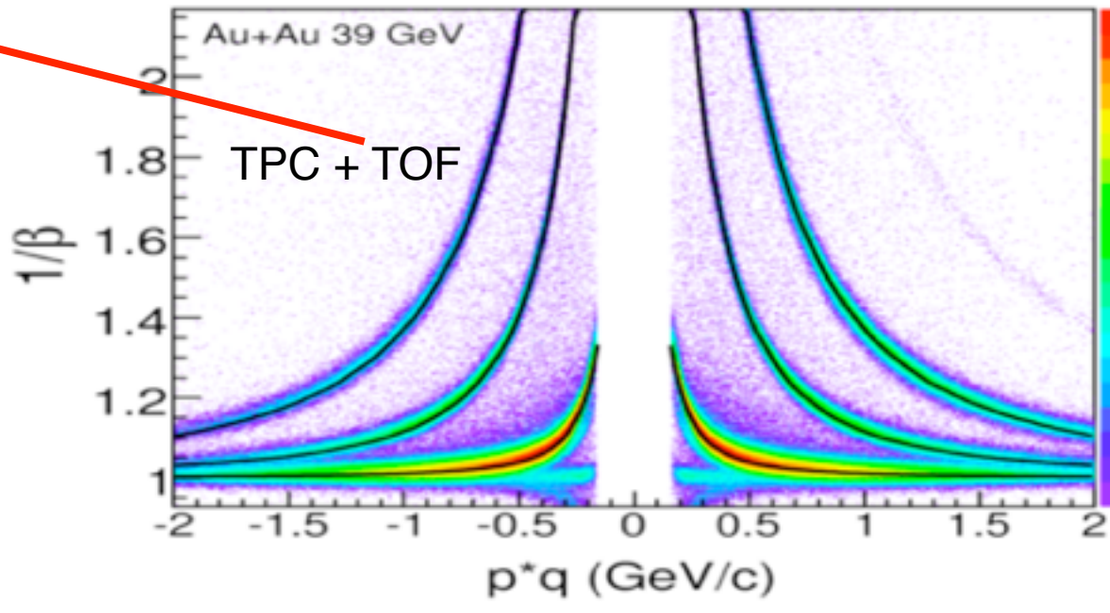
Capability to measure correlations,

Versatility in *symmetric* p+p, d+Au, Au+Au collisions spanning √s = 7.7 - 500 GeV.

STAR - Today

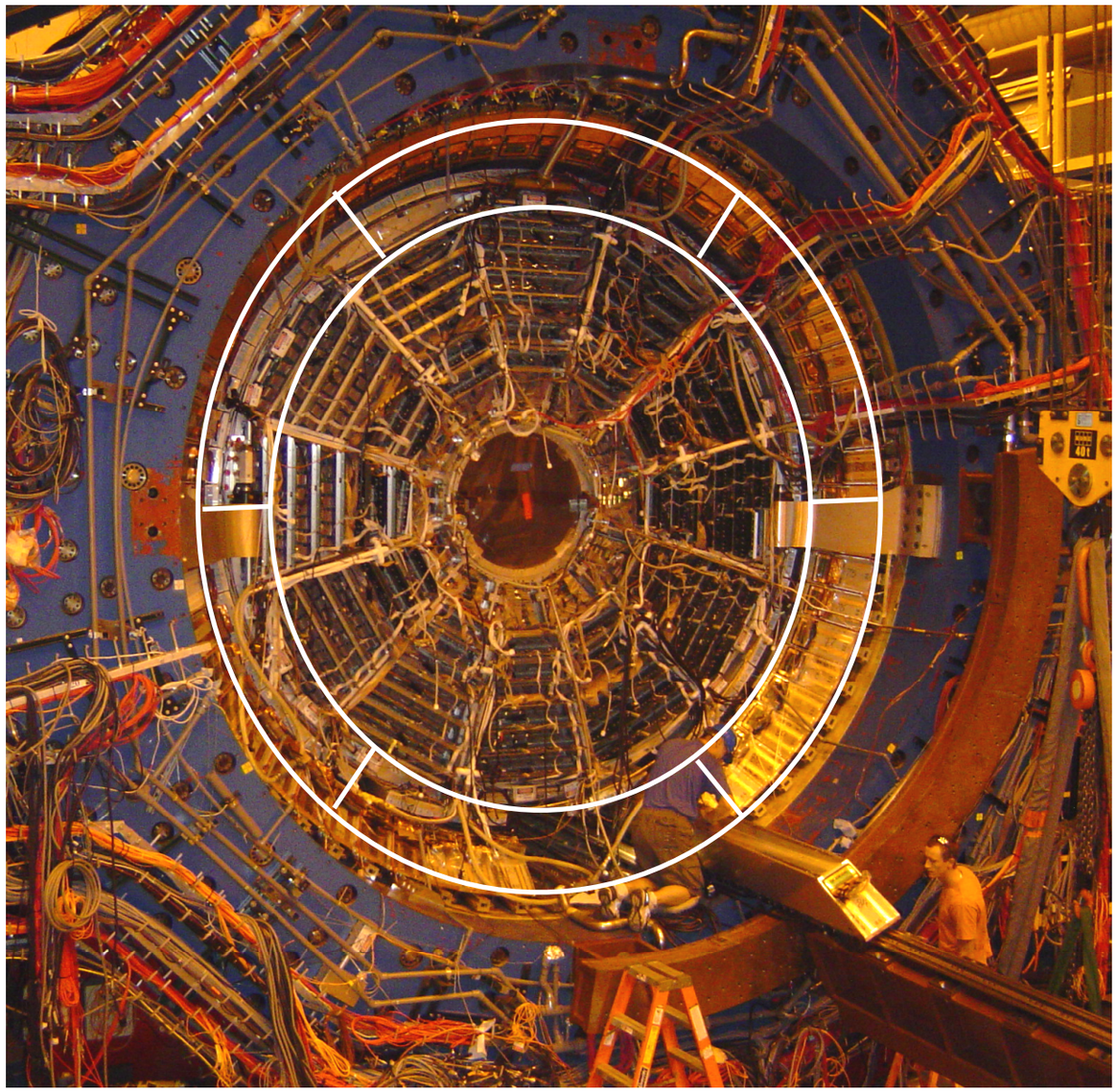






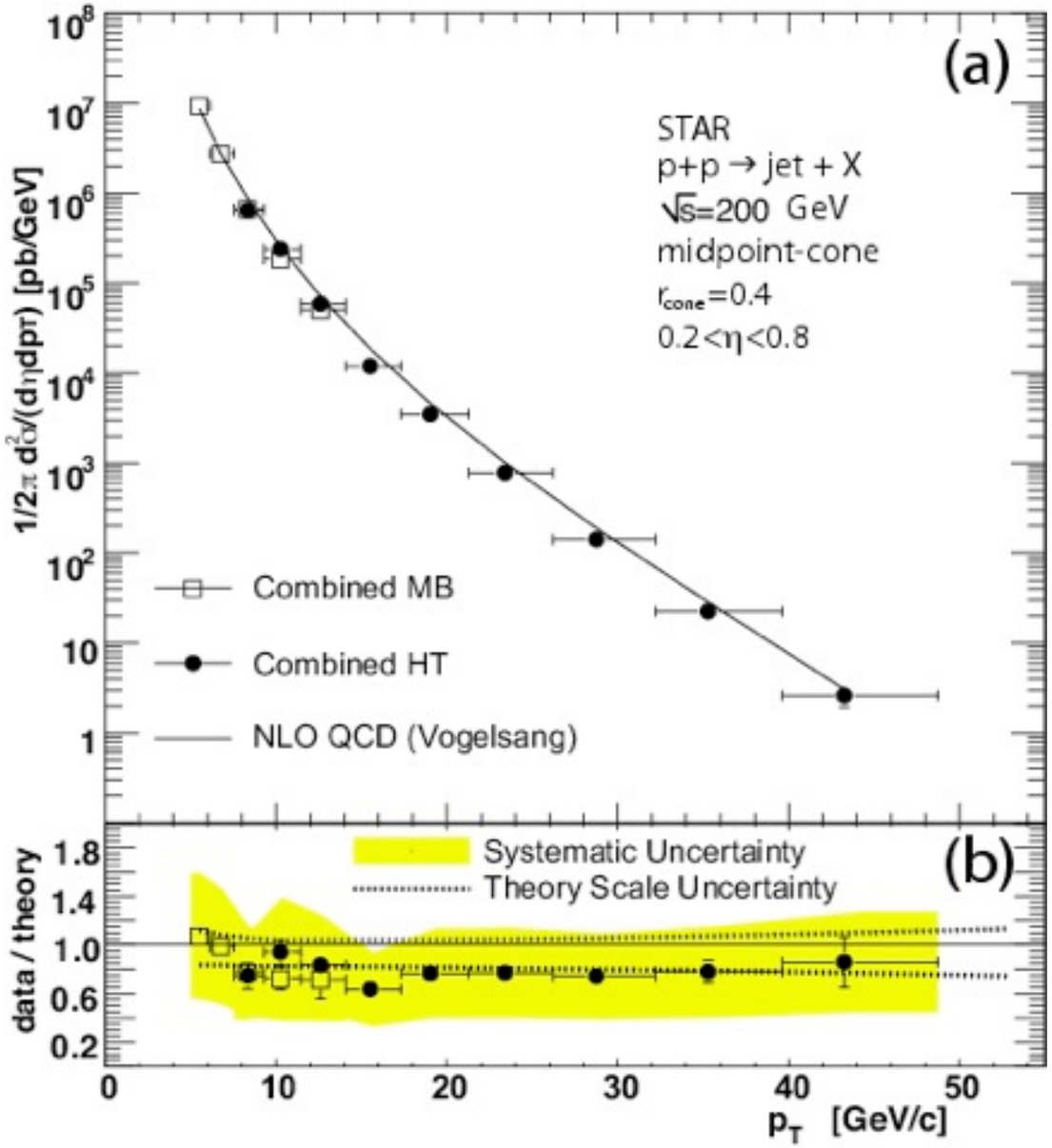
Mid-rapidity Particle Identification capability via dE/dx and ToF

STAR - Today



TPC: - charged track measurement
over 2+ units in pseudo-rapidity

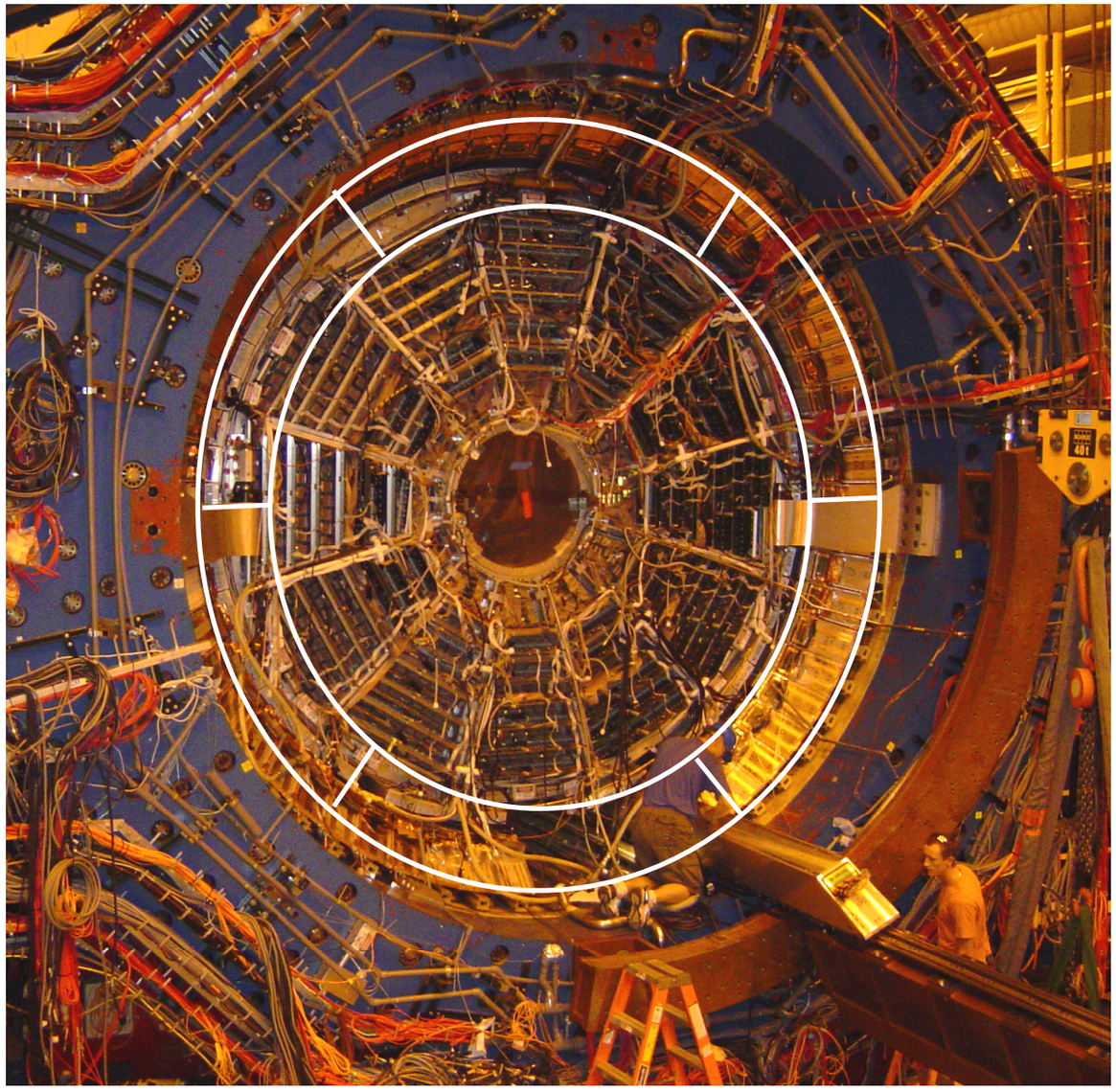
EMCs: - neutral energy measurement
over an even wider range,
- triggering



Phys. Rev. Lett. 97, 252001 (2006)

Jet capability.

STAR - Today



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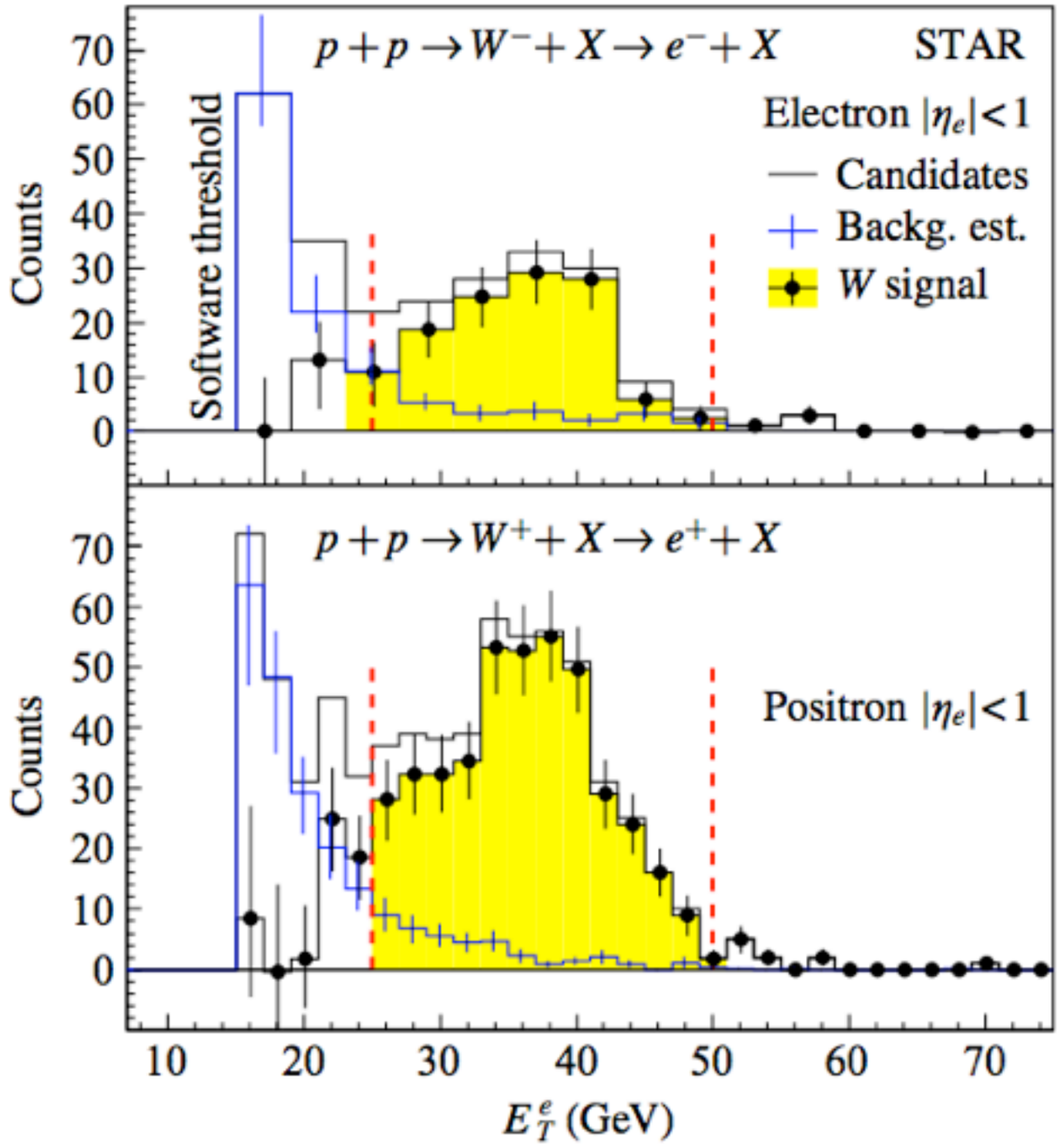
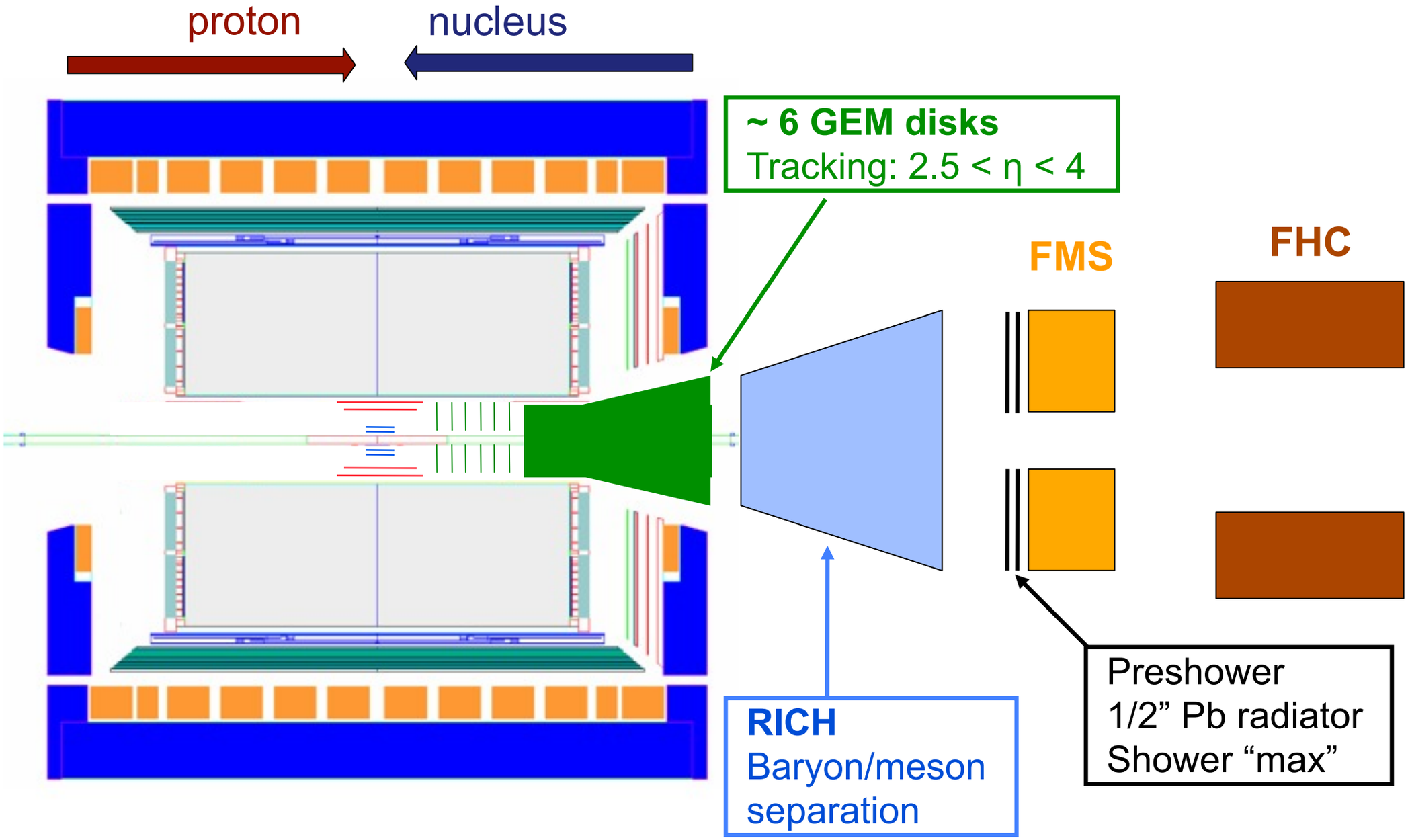


Phys. Rev. Lett. 106, 062002 (2011)

Electrons to very high momentum.

STAR - Decadal Plan



STAR near-term HFT, MTD - Heavy-Ion driven upgrades
FGT - W-physics driven

Longer-term driven by forward spin physics, p(d)+A, DY; tracking, *e/h, γ/π⁰*, baryon/meson

4) Any plans or interest your Collaboration has in adapting your detector or detector subsystems (or detector R&D) to study electron-nucleon and electron-ion collisions with an eventual eRHIC upgrade. This is relevant only near the end of the decade addressed here, but will be important for planning purposes. (We may well be forced by financial or environmental considerations, even for a first MeRHIC stage, to consider options in which acceleration of the electron beam is carried out around the RHIC tunnel, requiring some scheme for getting an electron beamline through or around PHENIX and STAR. So it's worth considering if there is some way you could make use of the e-p and e-A collisions if we provided them.)

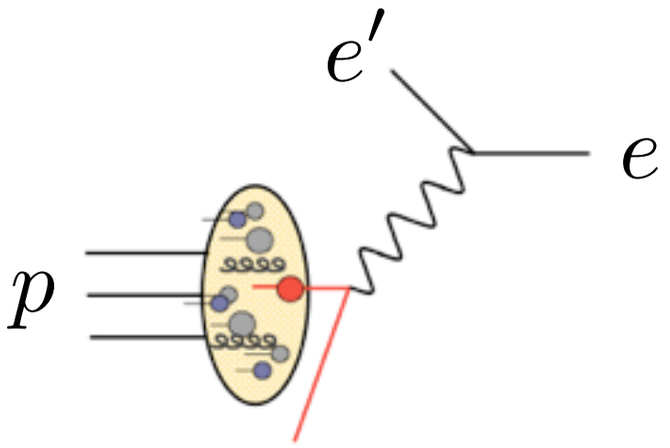
DIS - definitions, invariants

To get the angles deconfused:

$$e = (0, 0, -E_e, E_e)$$

$$e' = (E'_e \sin\theta'_e, 0, E'_e \cos\theta'_e, E_e)$$

$$p = (0, 0, E_p, E_p)$$



i.e. angles are defined *w.r.t. the hadron beam direction* (HERA-like).

Relevant invariants:

$$s = (e + p)^2$$ Square of total c.m. energy

$$q = e - e' \quad Q^2 = -(e - e')^2$$ Square of (4-)momentum transfer

$$x = \frac{Q^2}{ys}$$ Bjorken-x, ~parton mom. fraction

$$y = (q.p)/(e.p)$$ Fractional energy transfer

x, Q ^{2} can be reconstructed from the scattered electron, the “current jet”, or hybrids.

DIS - definitions, invariants

To get the angles deconfused:

$$e = (0, 0, -E_e, E_e)$$

$$e' = (E'_e \sin\theta'_e, 0, E'_e \cos\theta'_e, E_e)$$

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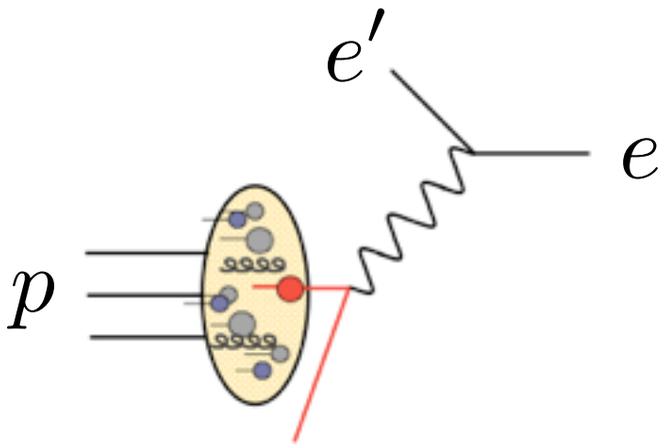


i.e. angles are defined *w.r.t. the hadron beam direction* (HERA-like).

Also:

$$y = \nu / \nu_{\mathrm{max}}$$ Fractional energy transfer

$$\nu = q \cdot p / m_{\mathrm{p}}$$ Energy of the current jet in the target rest frame

$$\nu_{\mathrm{max}} = \frac{s}{2m_{\mathrm{p}}}$$ *A polarized EIC will vastly exceed capability JLab, Hermes, ...*

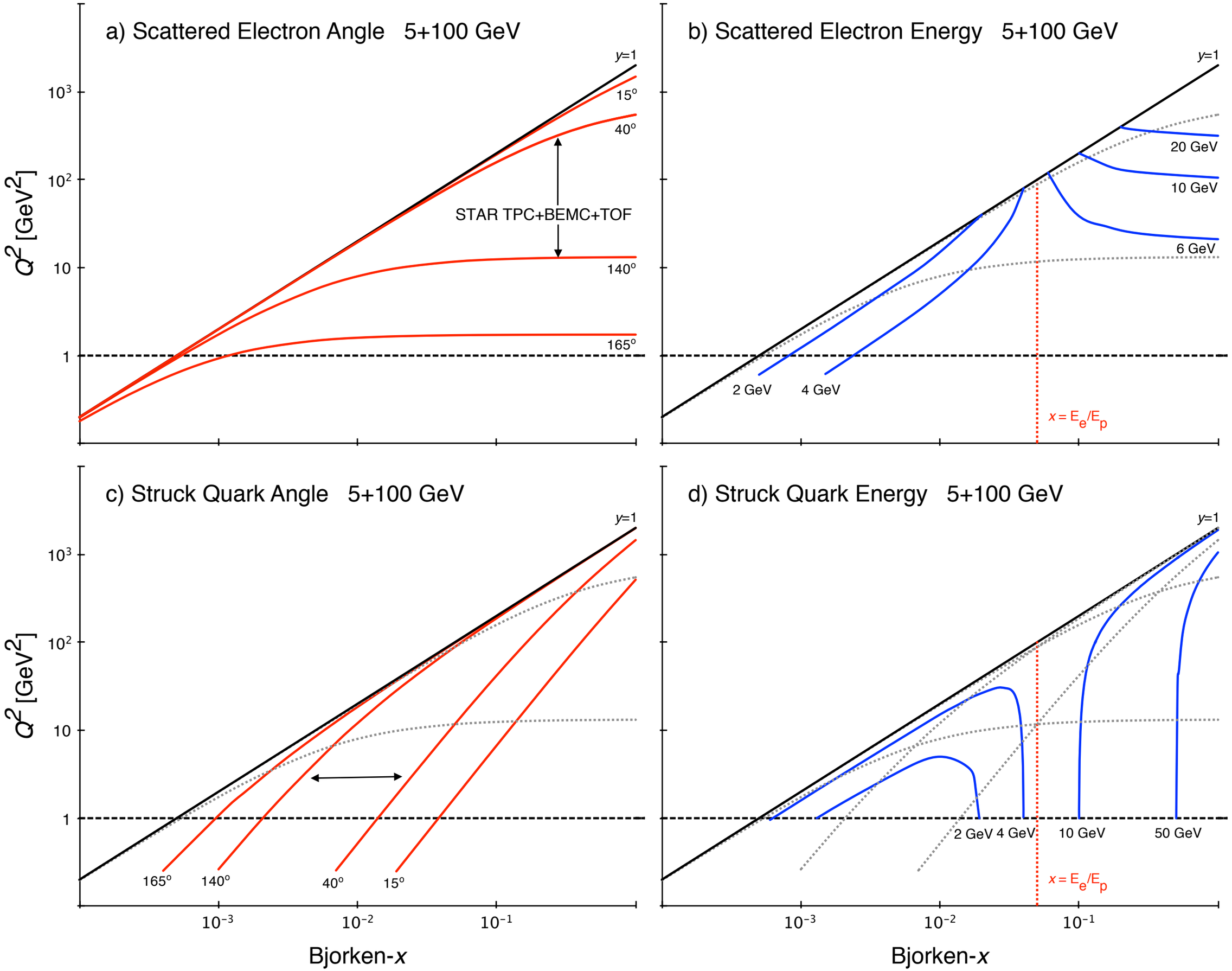
DIS - eSTAR

a) Scattered Electron Angle 5+100 GeV

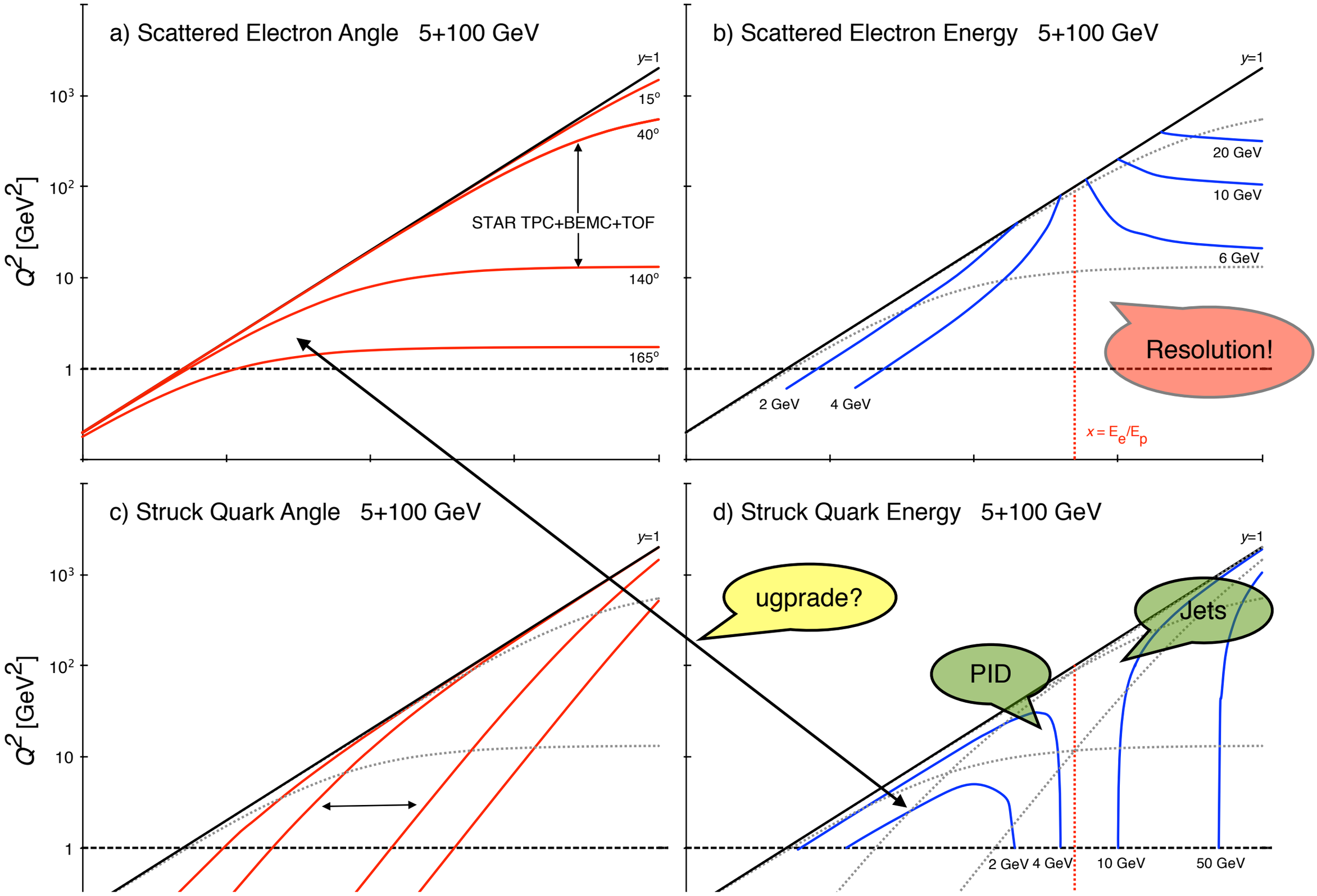
b) Scattered Electron Energy 5+100 GeV

c) Struck Quark Angle 5+100 GeV

d) Struck Quark Energy 5+100 GeV



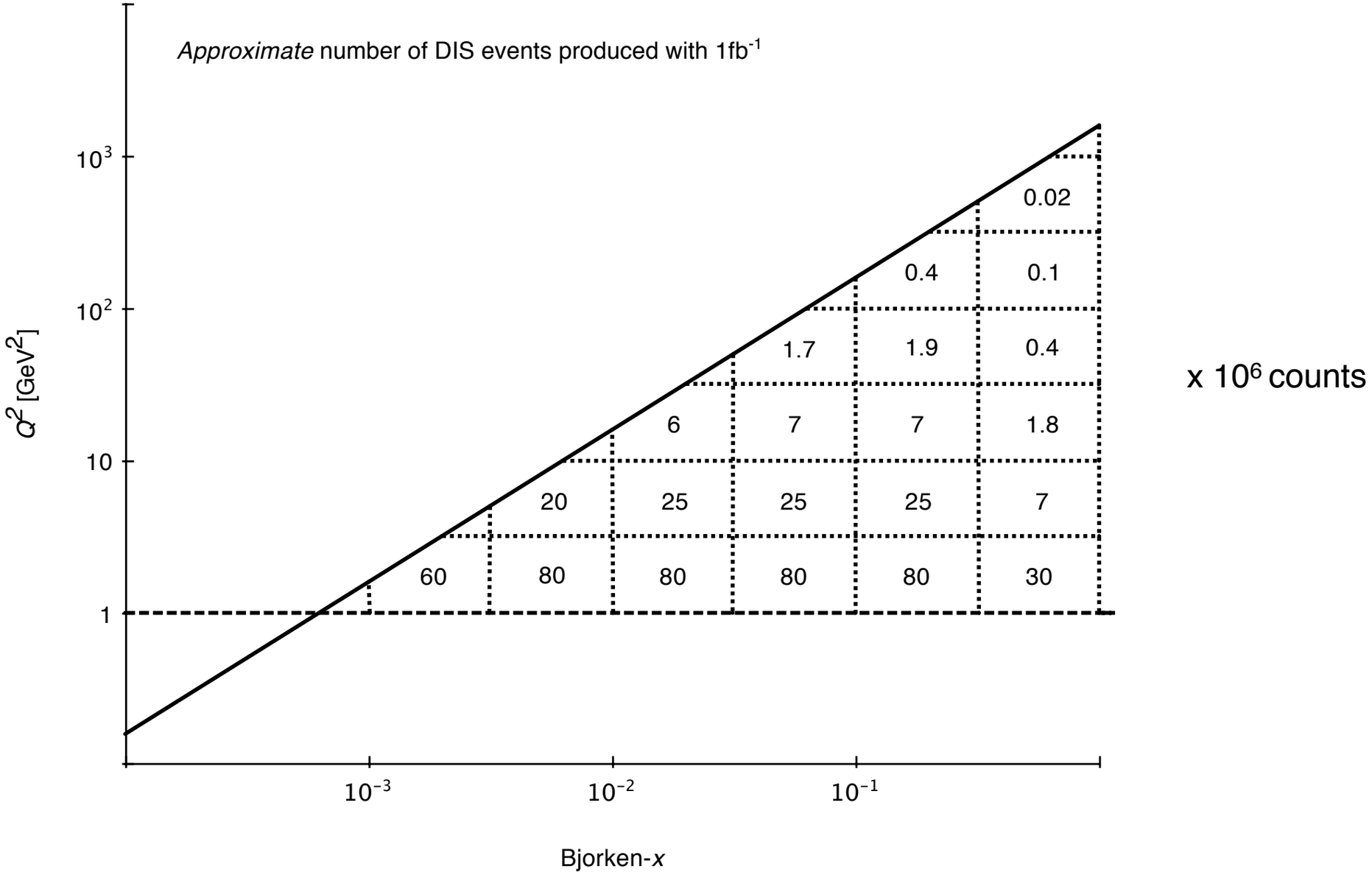
DIS - eSTAR



Electron beam in Yellow, Hadron beam in Blue,

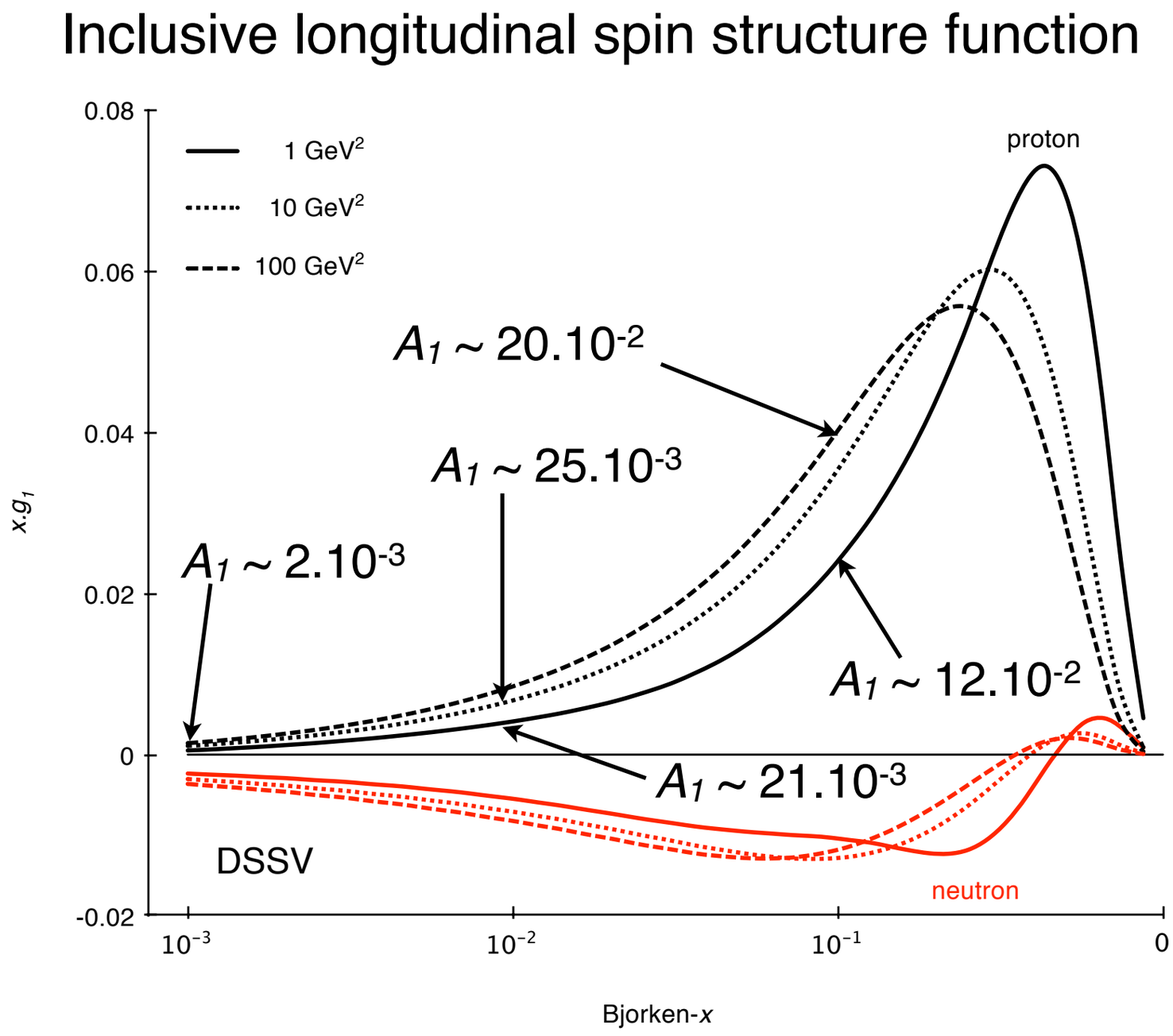
Task ahead: turn balloons into projected *accuracy (not 'just' precision)*.

Intermezzo - measurement *accuracy*



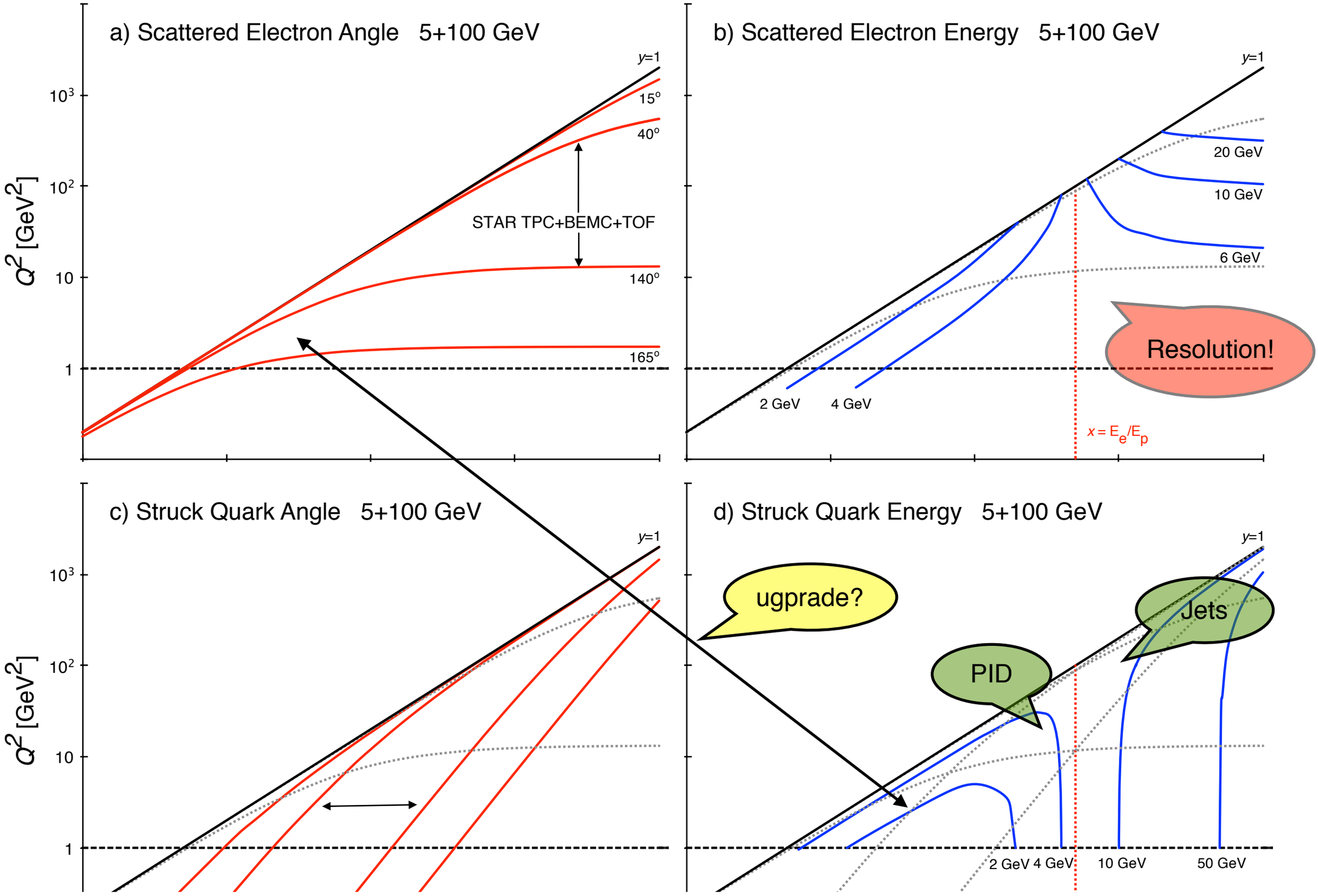
Many inclusive measurements will become systematics dominated.

Intermezzo - measurement *accuracy*



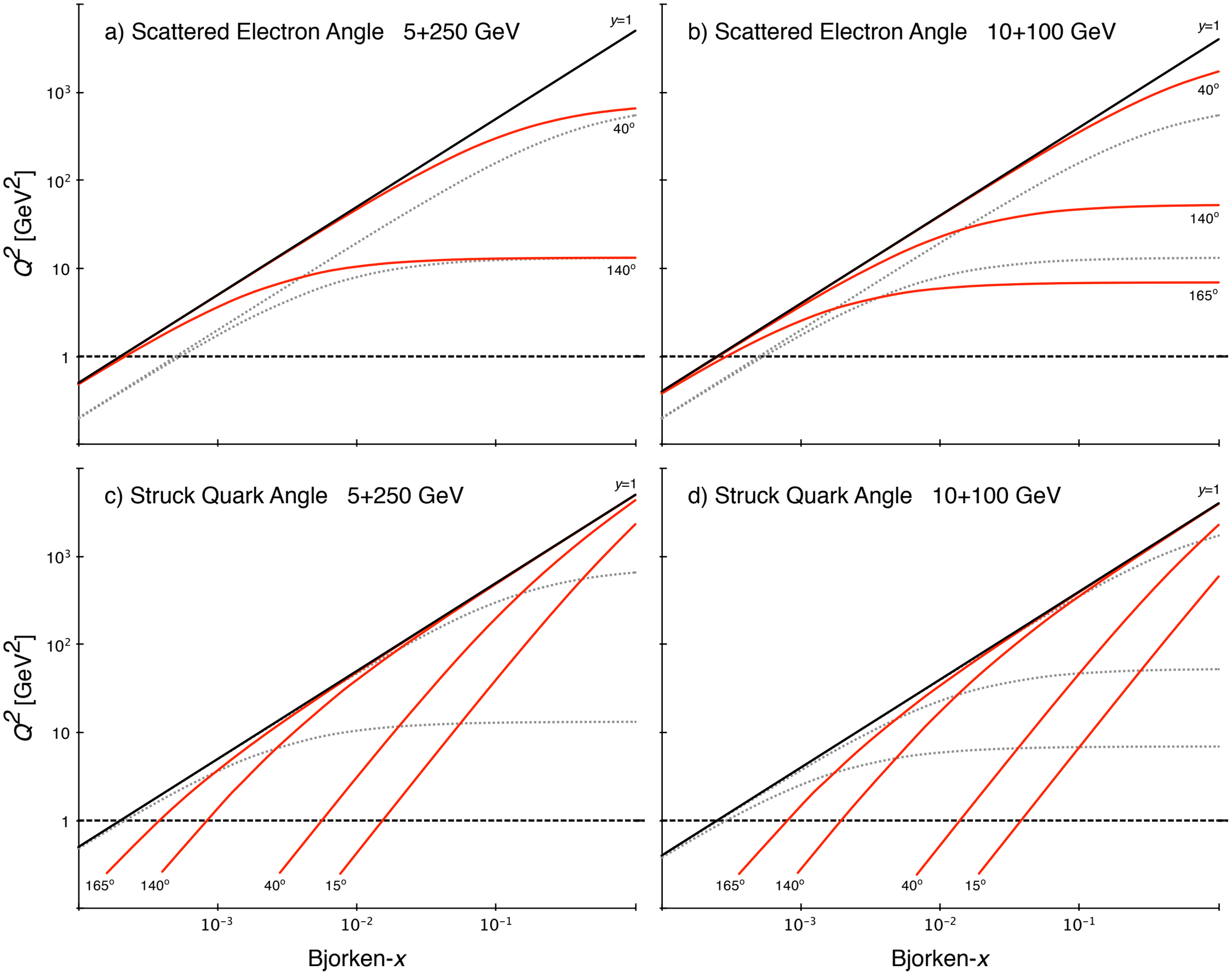
Polarimetry, relative and absolute luminosity, ...

DIS - eSTAR

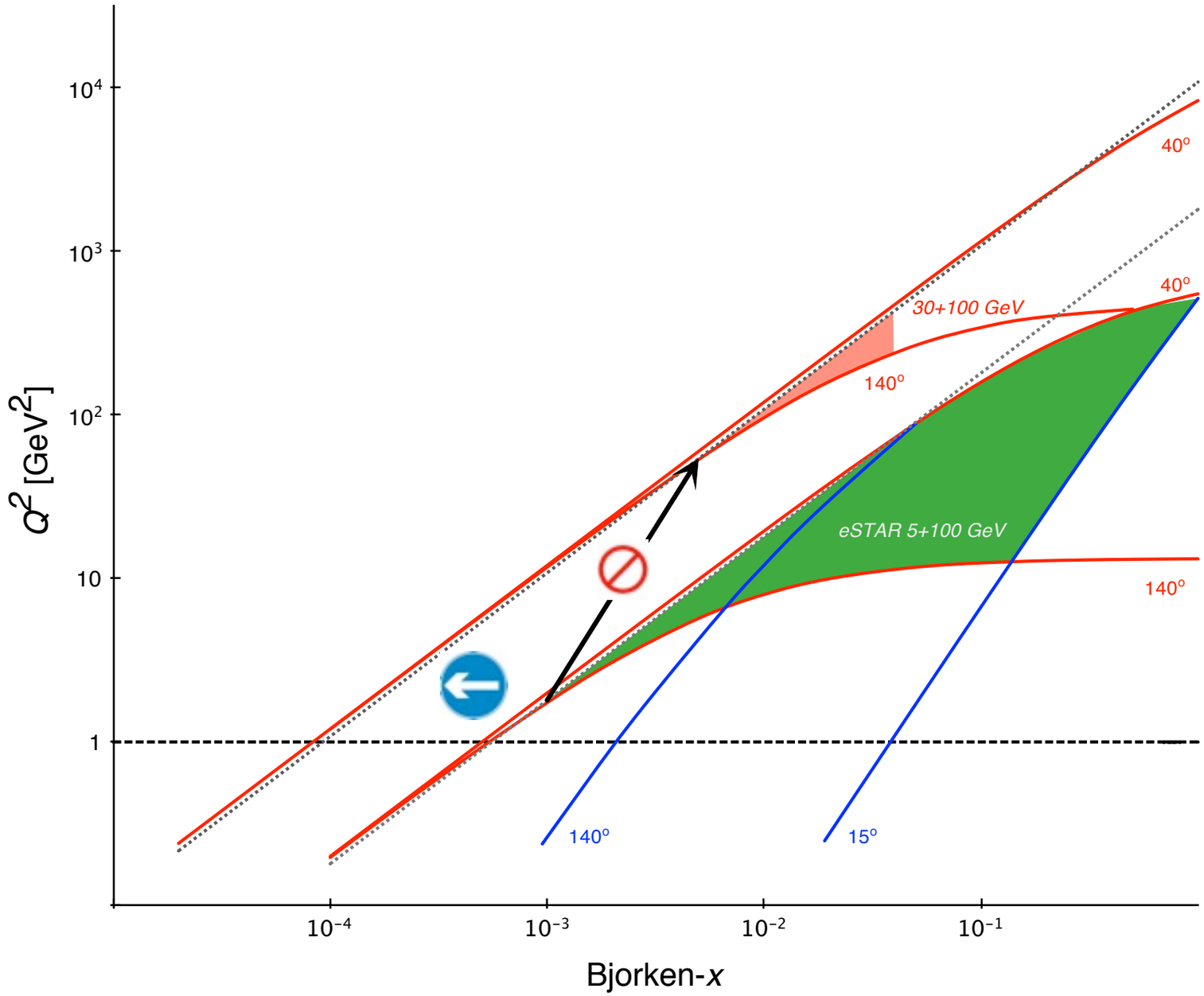


Back to eSTAR kinematics, how do these scale with beam energies?

DIS - eSTAR

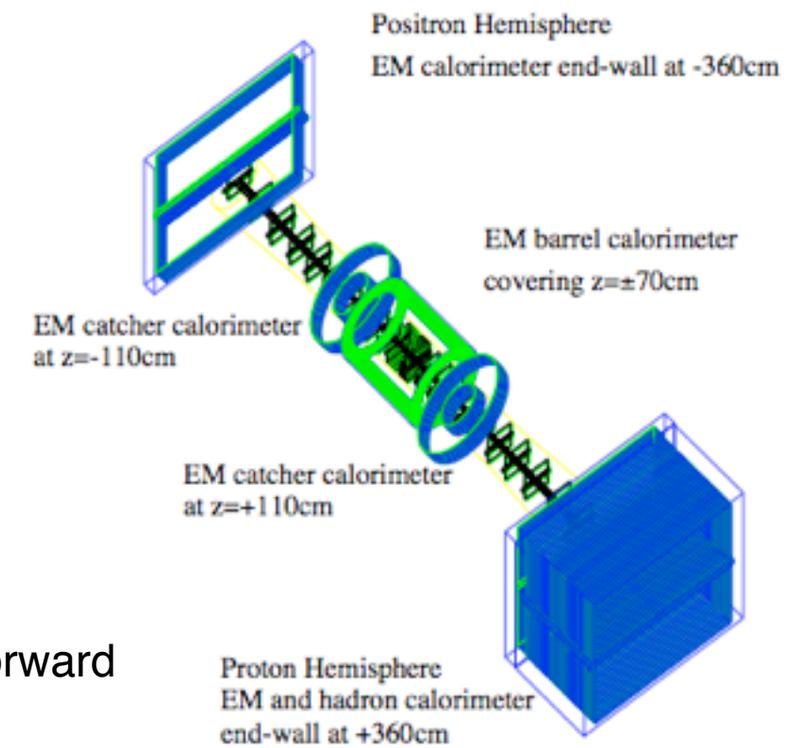

a) Scattered Electron Angle 5+250 GeV
b) Scattered Electron Angle 10+100 GeV
c) Struck Quark Angle 5+250 GeV
d) Struck Quark Angle 10+100 GeV
y=1
40°
140°
165°
15°
Q^2 [GeV^2]
10^3
10^2
10
1
10^{-3}
10^{-2}
10^{-1}
Bjorken-x

Intermezzo - Beam Energy *and* Detector



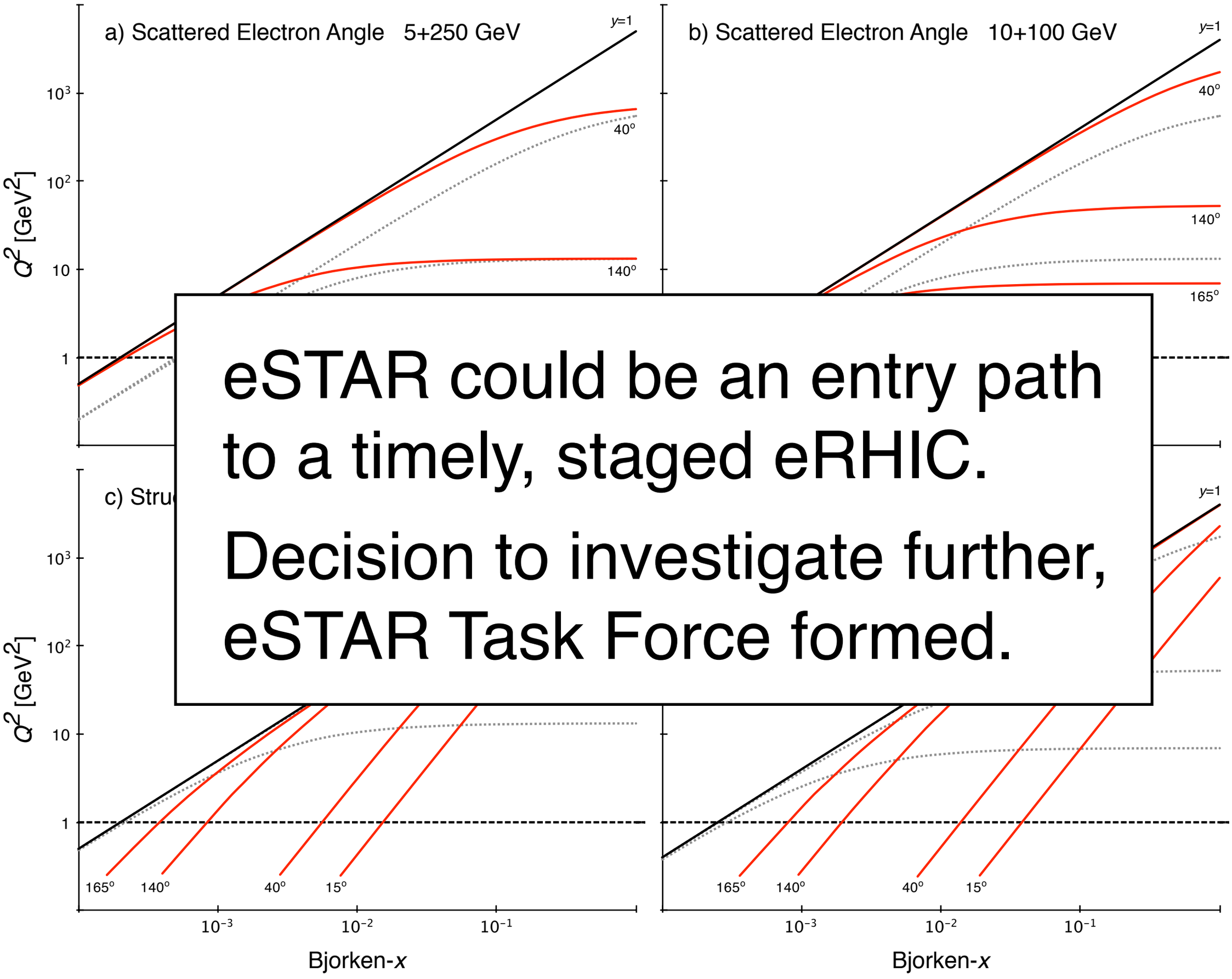
Staging of beam energies <u>requires</u> commensurate investments in detectors.

This of course *no* surprise, recall:



I. Abt, A. Caldwell, X. Liu, and J. Sutiak, “A Detector for Forward Physics at eRHIC - Feasibility Study”, hep-ex 0407053

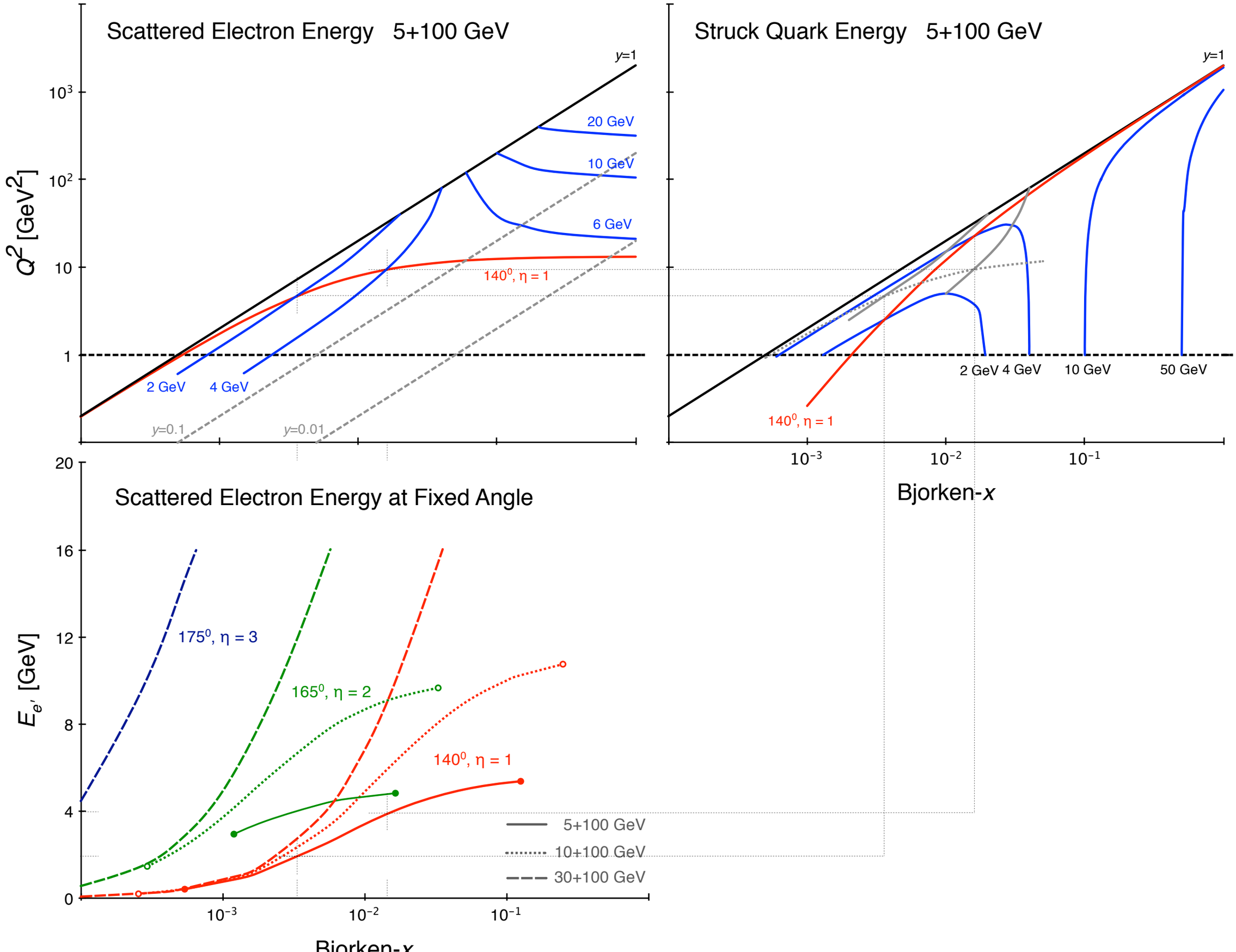
DIS - eSTAR



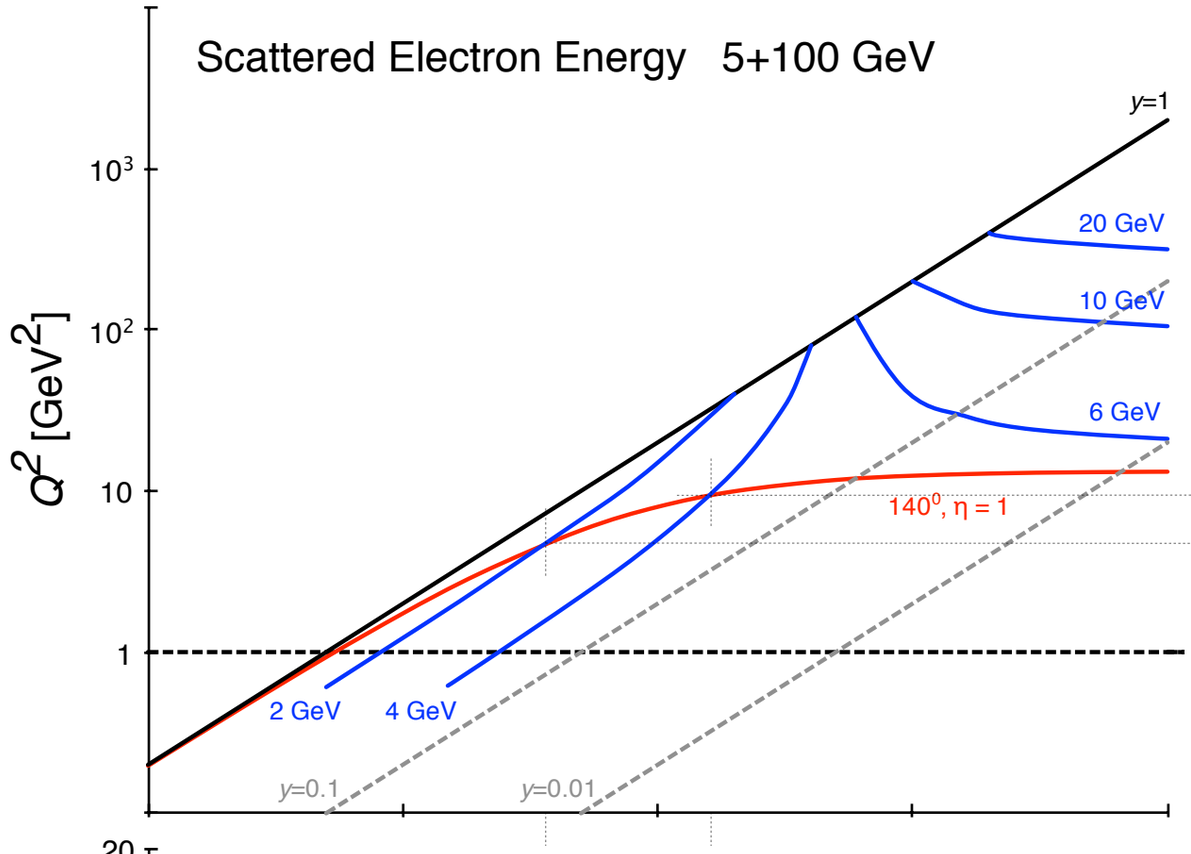
eSTAR could be an entry path to a timely, staged eRHIC.

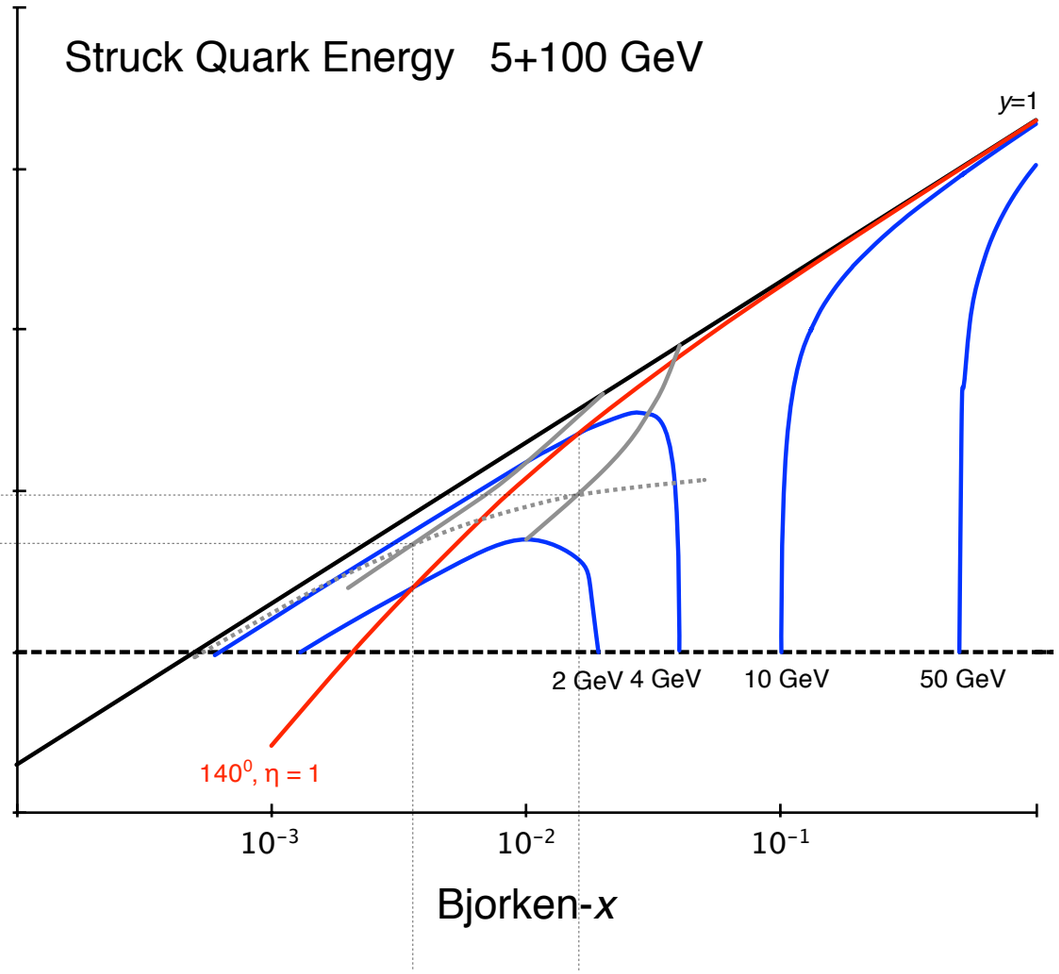
Decision to investigate further, eSTAR Task Force formed.

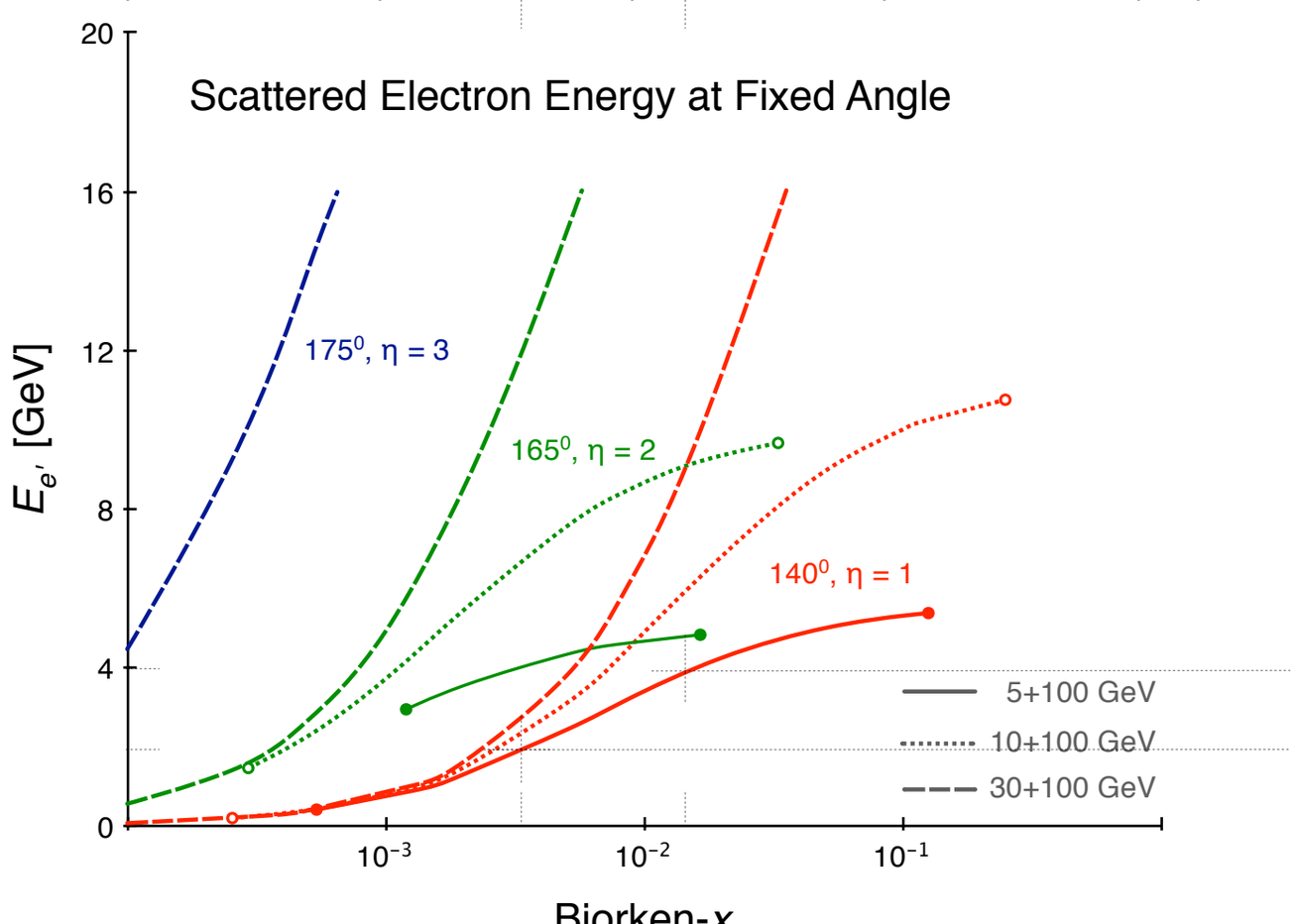
Towards an eSTAR Concept



Towards an eSTAR Concept







Bending radii ~m,

Sagitta ~mm (over 40cm),

At 140º, dx/x~2 implies:

dE/E~0.5 at x ~ 10^{-3}

dE/E~0.3 at x ~ 10^{-2}

dE/E~0.04 at x ~ 10^{-1}

At 165º, dx/x~2 implies dE/E~0.09 at 5.10^{-3}

Towards an eSTAR Concept

Observations:

1. STAR acceptance and PID capabilities appear a reasonable match to staged eRHIC,
   for *low* electron beam energies and *all* hadron beam energies,
   sensible to accept the constraints, and work towards quantitative capability projections,
2. Small-*x* is principally about *low-energy* scattered electrons,
3. The radius of curvature, however, remains comparable to the detector diameter or larger,
4. There is no substitute for √s or *high* electron beam energies to reach smallest-*x.*
5. IR and (decadal plan) hadron-side of STAR are at odds.

Hence, an upgrade for the initial electron beam energy/energies:

1. is likely a track-based spectrometer rather than a calorimeter,
2. must be low-mass,
3. should combine momentum measurement with e/h separation, ideally full PID,
4. trigger,
5. be(come) compact.

Investigate possibilities with detector at radii within the TPC inner field-cage,

- HFT-pixel not considered a constraint (at this time),
- threshold (gas-)Cherenkov combined with tracking.

Investigate SciFi calorimetry (O. Tsai et al).

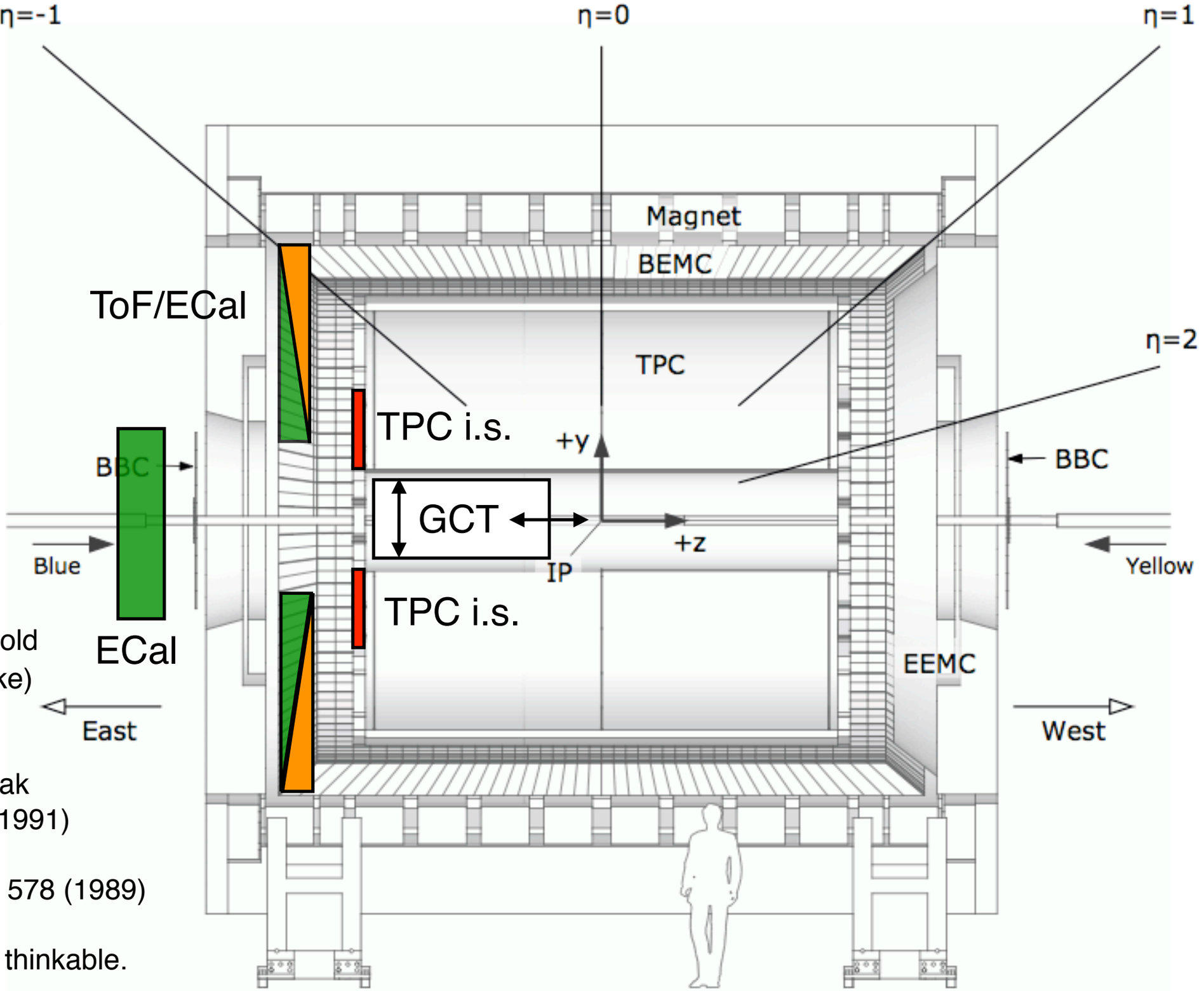
Towards an eSTAR Concept - Electron Side

ToF: π , K identification, t_0, electron (Z.Xu)

ECal: 5 GeV, 10 GeV, ... electron beams

GCT: a compact tracker with enhanced electron capability;

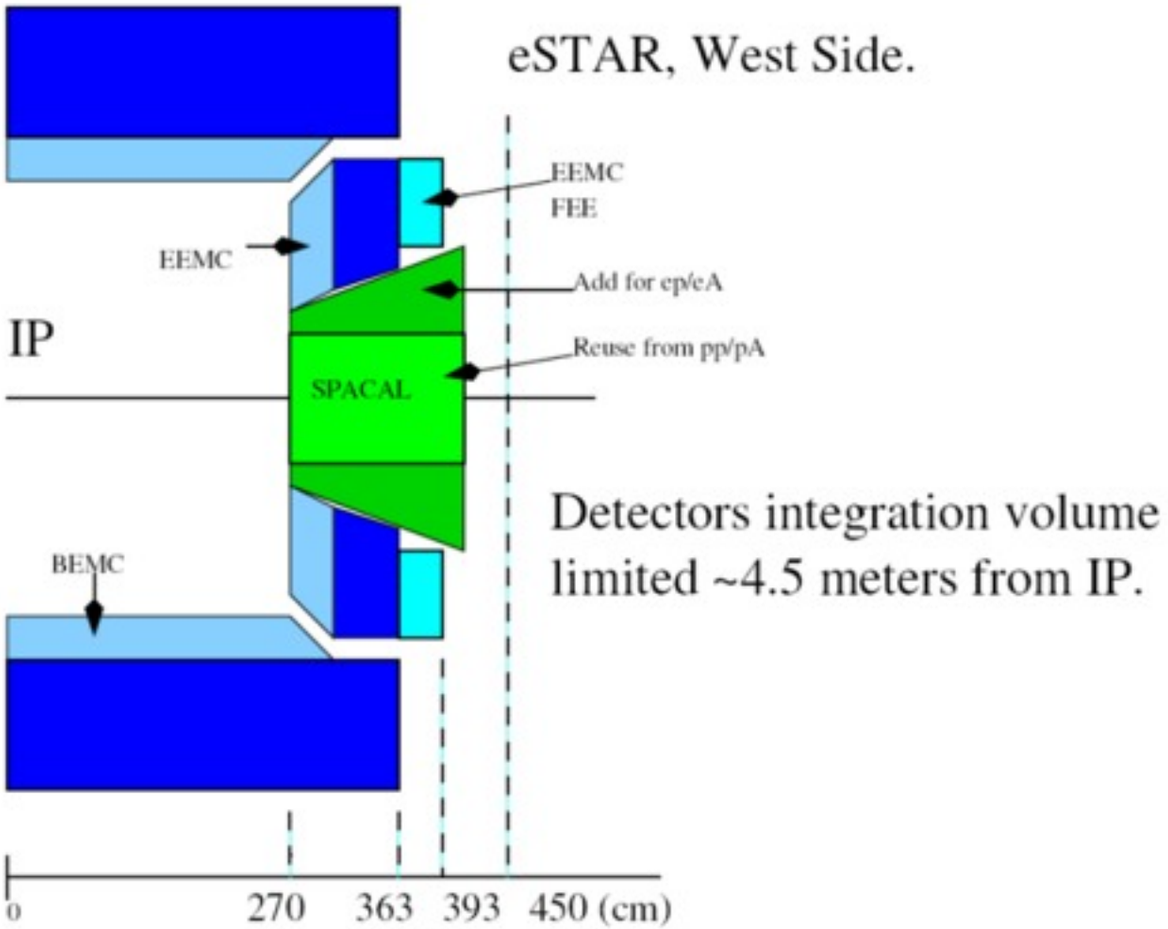
- seeks to combine high-threshold (gas) Cherenkov with TPC(-like) tracking (N. Smirnov, E.S.)
- Indeed, similarities with
  - Y. Giomataris and G. Charpak NIM A310 (1991) 589-595 (1991) PHENIX HBD
  - P. Nemethy et al. NIM A328 578 (1989)
- will certainly involve R&D.
- Conventional alternatives are thinkable.

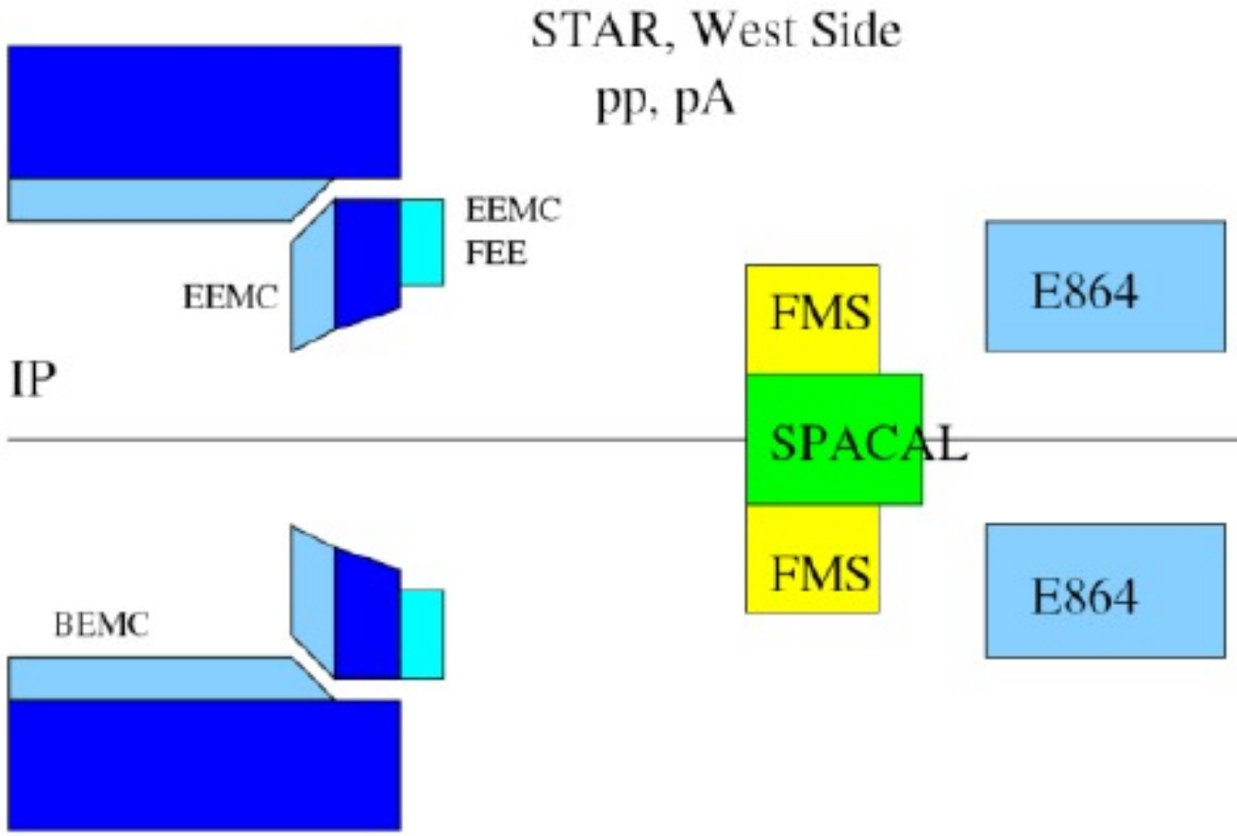


Simulations ahead.

Towards an eSTAR Concept - Hadron Side

Two ‘extremes’:





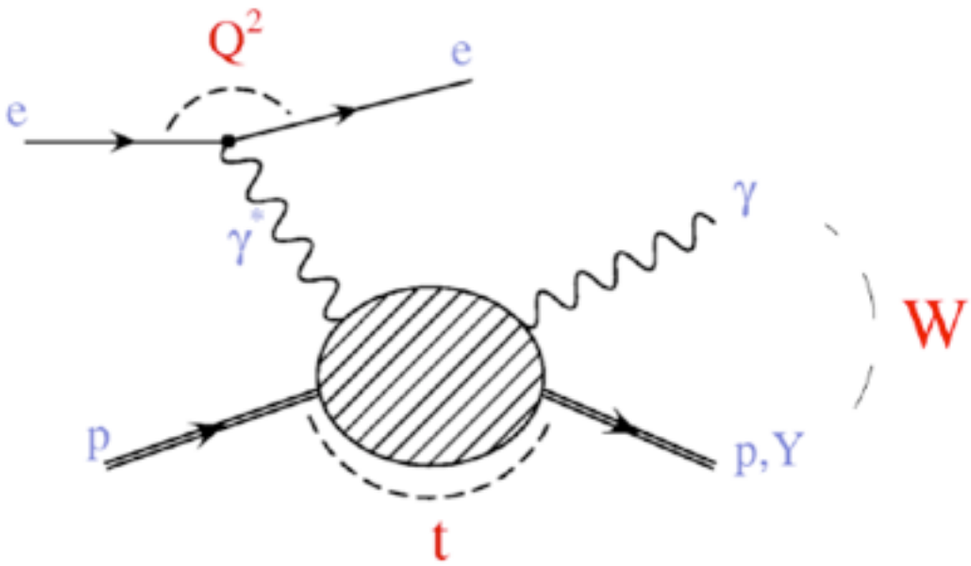
Trackers, RICH, preshower/showermax not shown

will evolve. This said, 4.5 m seems too restrictive.

Simulations ahead.

Towards an eSTAR Concept - Beyond DIS

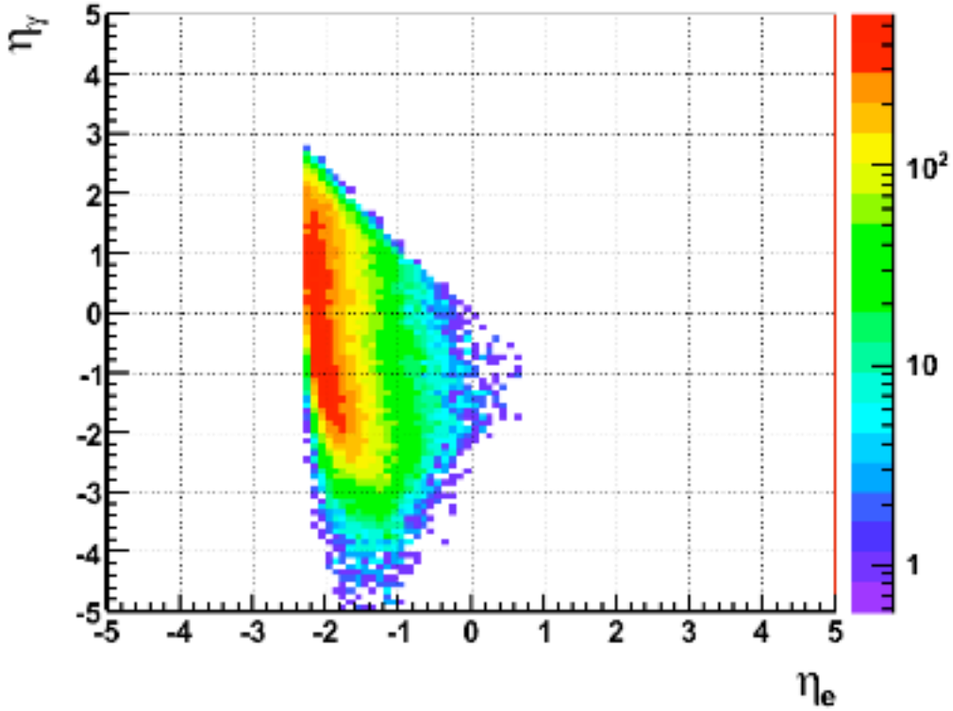
Investigate Deeply Virtual Compton Scattering (J.H. Lee),

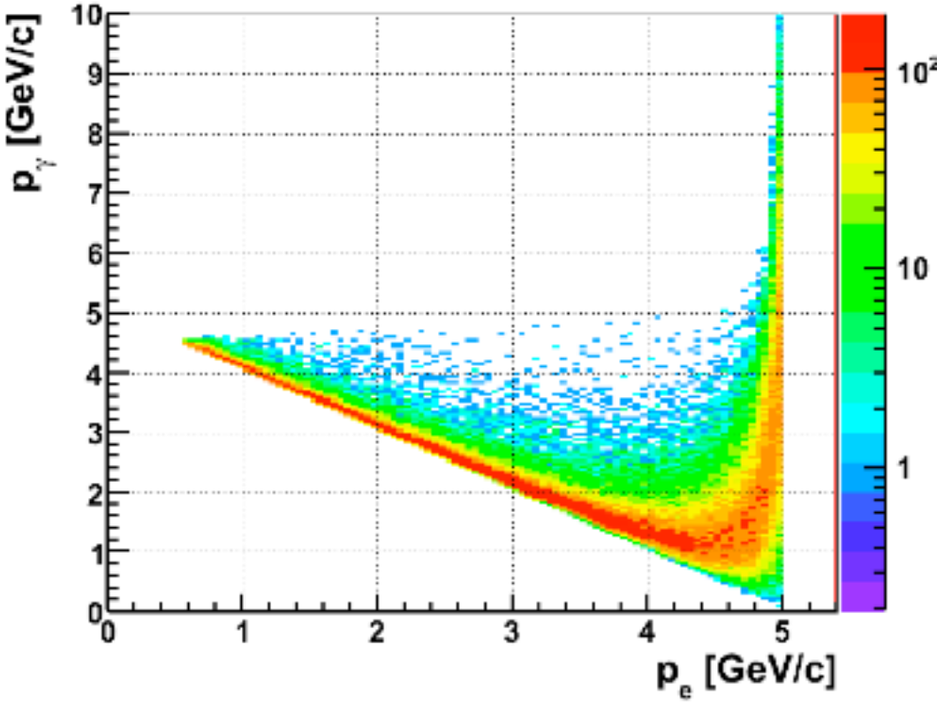


Requires measurement of electron, proton, and photon,

Proton requires Roman Pot, intimately tied to I.R. design,

Electron requirements appear similar to DIS, 5x50GeV:





Photoproduction is certainly closely tied to I.R. design as well, no tangible progress yet.

...

Summary

STAR has proven to be a versatile instrument in A+A, d+A, p+p for √s = 7.7-500 GeV,

Task force formed to further investigate the possibility to extend even to asymmetric e+p and e+A collisions for the *initial* eRHIC energy/energies,

Initial concepts exist, simulations, iteration, to follow,

EIC task force, IR design, timing should work to common goal,

Generic R&D:
- SciFi calorimetry
- candidate: compact tracker with enhanced electron capability

Polarimetry, luminosity are very important, but not (likely) part of STAR mid-rapidity.